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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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Announcement

Volume 2 of the JOURNAL OF SEDIMENTARY PETROLOGY will contain three numbers, to appear in April, August and December, 1932. The number of pages will be enlarged, as compared with Volume 1, and as contributions in this field, accepted for publication, increase, there is prospect of more frequent issue of the Journal. Papers offered for publication should be transmitted to the Editor or to any member of the Editorial Staff.

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APRIL, 1932

SEDIMENTATION IN MASSACHUSETTS BAY

A. C. TROWBRIDGE[1] AND F. P. SHEPARD[2]

ABSTRACT

Most of the sediment in process of deposition in Massachusetts Bay is derived by wave erosion from glacial drift or from bedrock on the coast and bottom of the Bay. Very little material is contributed from inland positions by streams or wind. The main agents of transportation are storm waves and currents and tidal currents. The sediments consist of silt, sand, and gravel. Bare bedrock occurs locally in belts at short distances from the shore. There is evidence of both emergence and submergence of the shoreline. Conditions at different places in the Bay and bottom samples in series from these same places are described in some detail and interpreted.

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INTRODUCTION

The primary purpose of this paper is to present specific data on sedimentation in a part of the modern shallow seas, the data being obtained through the application of laboratory methods to the study of sediments. In addition to presentation of the objective results, however, the liberty has been taken of making tentative interpretations of the origin and conditions of deposition of the marine sediments in the selected area. These interpretations are based on the evidences supplied by the textural, mineral, and shape analyses of the bottom samples. It is hoped that such remarks as are appended to the data may be of some small value in pointing out the possibilities of interpretation of such data, even though they may not be pertinent in all cases,

[1] University of Iowa, Iowa City.
[2] University of Illinois, Urbana.

because of lack of field knowledge and little experience with similar types of sediment.

COLLECTION OF SAMPLES

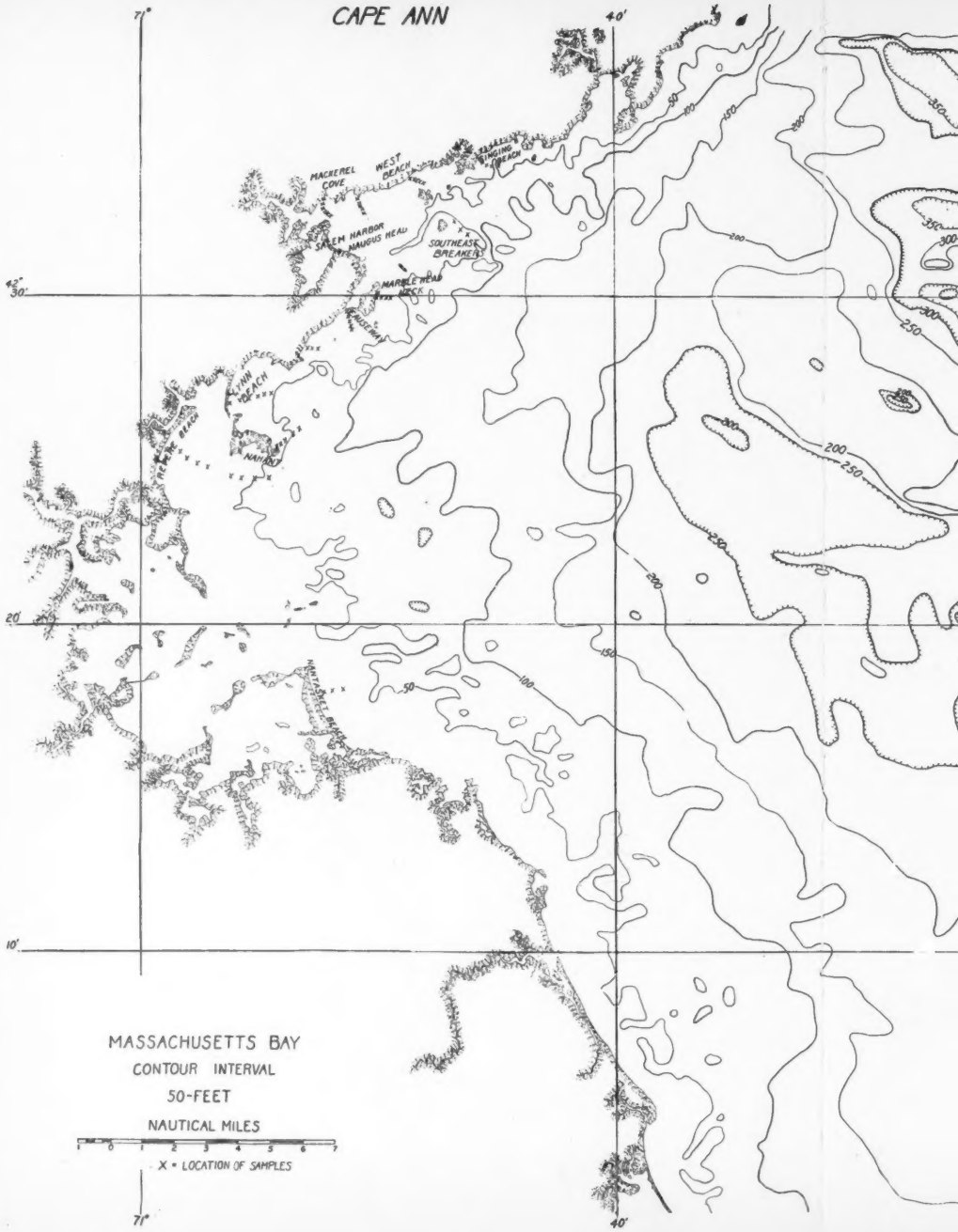
In the summer of 1922, the junior writer, through the kindness of Mr. T. H. Shepard, was given the use of the sloop *Katherine* to collect samples of sediment from Massachusetts Bay. The *Katherine* belongs to the class of racing cruising yachts known as the "New York 40-footers." She has a large beam for a boat of her length and is seaworthy. A somewhat flaring bow prevents the waves from washing over the deck except in very rough weather. As a sailing boat, she was highly desirable for the work. The devices used were telegraph snappers and a boat dredge. The former was found the more successful. It consisted of a weighted cylinder with a pair of jaws at the base. The jaws closed by a spring device which released the weight when they touched bottom. A sample not larger than a small egg was collected by this method. When the bottom was relatively hard, a small amount was caught. Some of the samples were not illustrative of the bottom, because a pebble held in the jaws let the fine material sift out.

When the wind was blowing hard, the taking of a sample needed considerable organization of the crew. The helmsman had to choose the right moment for luffing (heading into the wind) and could not prolong the action until the boat lost steerage-way because of the difficulty of getting back onto the course. Another member stood at the compass sights ready to take the bearing of known objects so as to ascertain the position of the sample. One man stood in the bow with the instrument set and hurled it forward when the progress was sufficiently checked. Another stood in the stern with the other end of the line and a reel to let it out as much as necessary and determine the depth of the water when the snapper was on bottom. Finally, someone had to hold the notebook and take down bearings, depth of water and other notes pertinent to the situation. As the ship was swung back on her course and began to keel over, the instrument had to be put away hurriedly and other things stowed so as not to be washed over board.

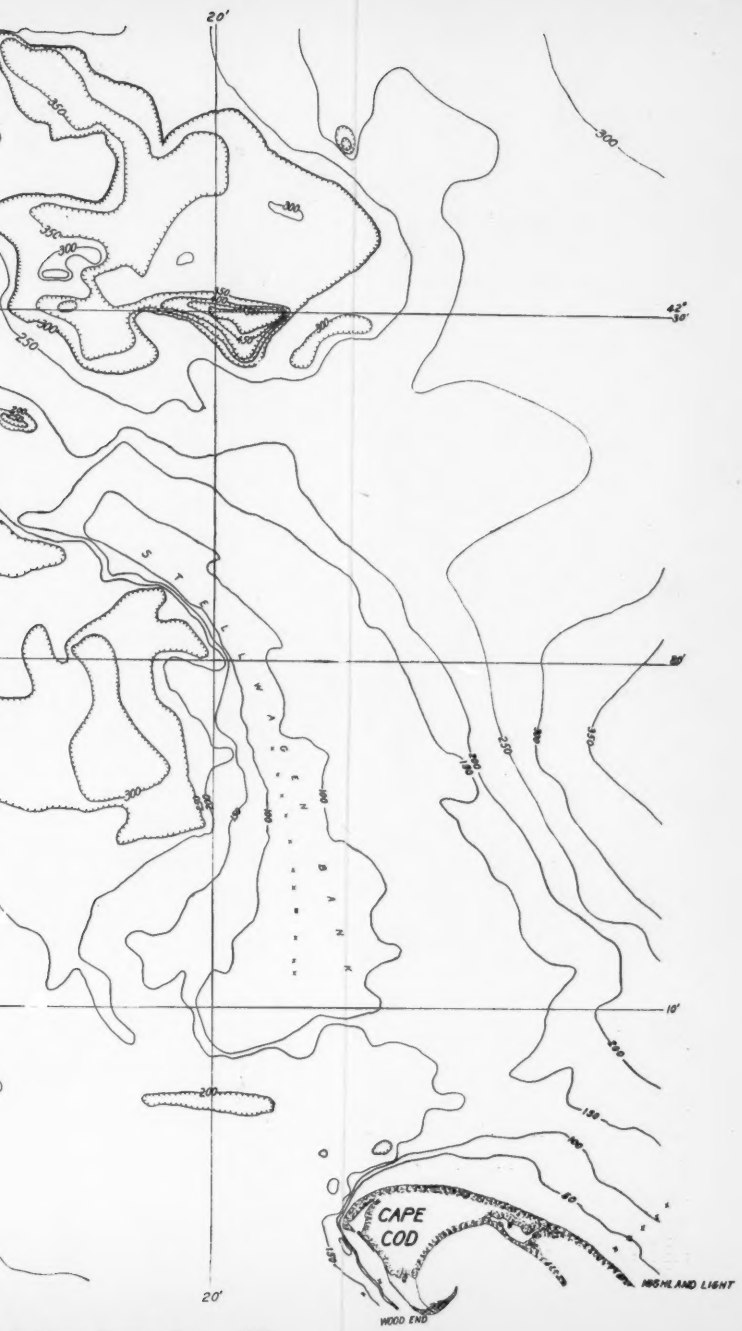
Most of the samples were taken serially, either from a beach outward to sea, from deep water inward to a beach, from the seaward border to the head of a bay, from land to land across the mouth of a bay, or in longitudinal and transverse lines from deep water to deep water across a bank. A total of fourteen different situations were studied in the field and are represented by series of samples in the paper. A total of 183 samples were collected in and near Massachusetts Bay, but not all of these were studied in the laboratory or are included in the present paper.

NATURE OF THE SEDIMENTARY ANALYSES

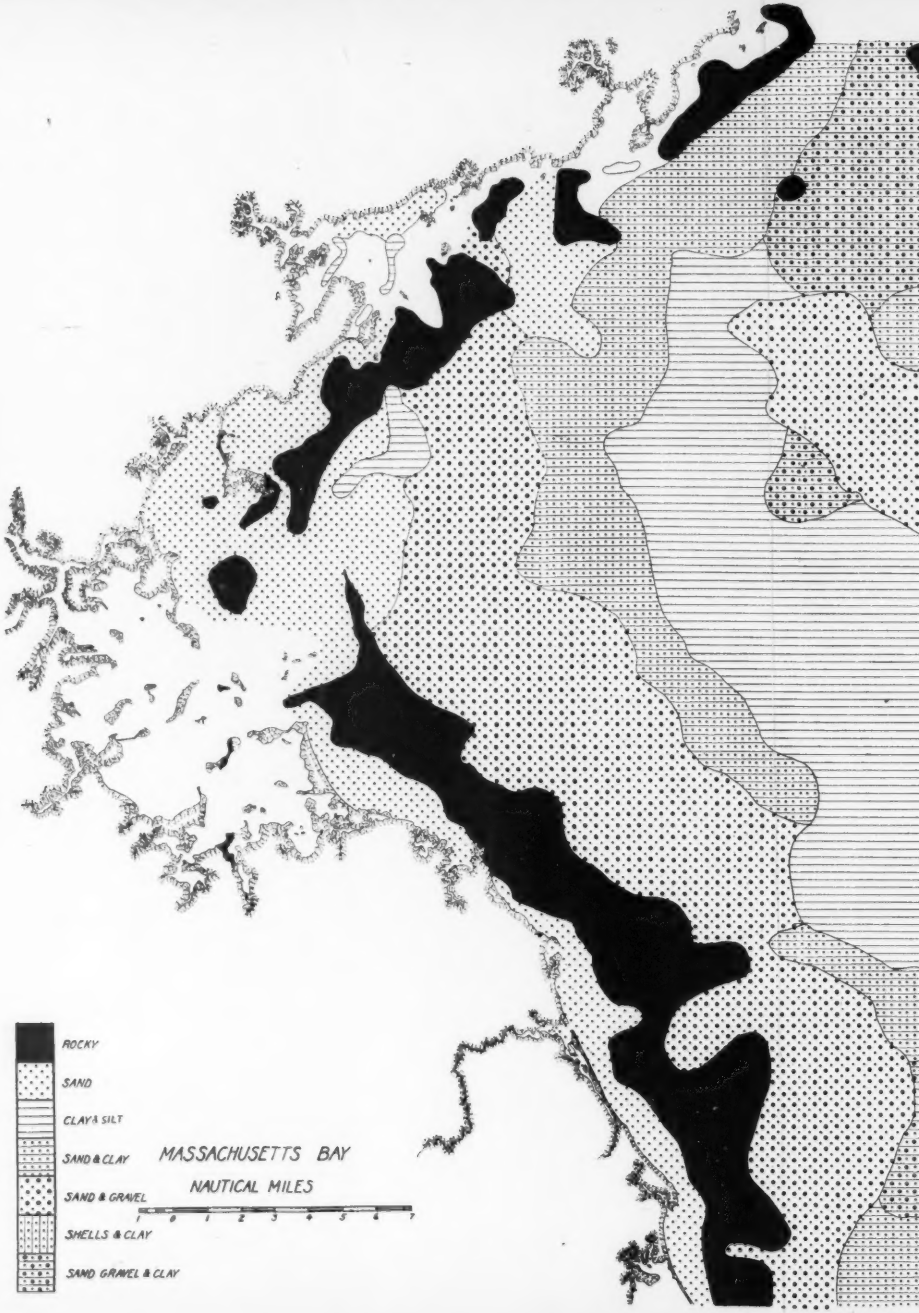
Complete analyses. Of the samples collected, twenty of the more critical ones representing fourteen of the



BATHYMETRIC MAP OF MASSACHUSETTS BAY. SOURCE, U. S. COA



U. S. COAST SURVEY CHART 1207.



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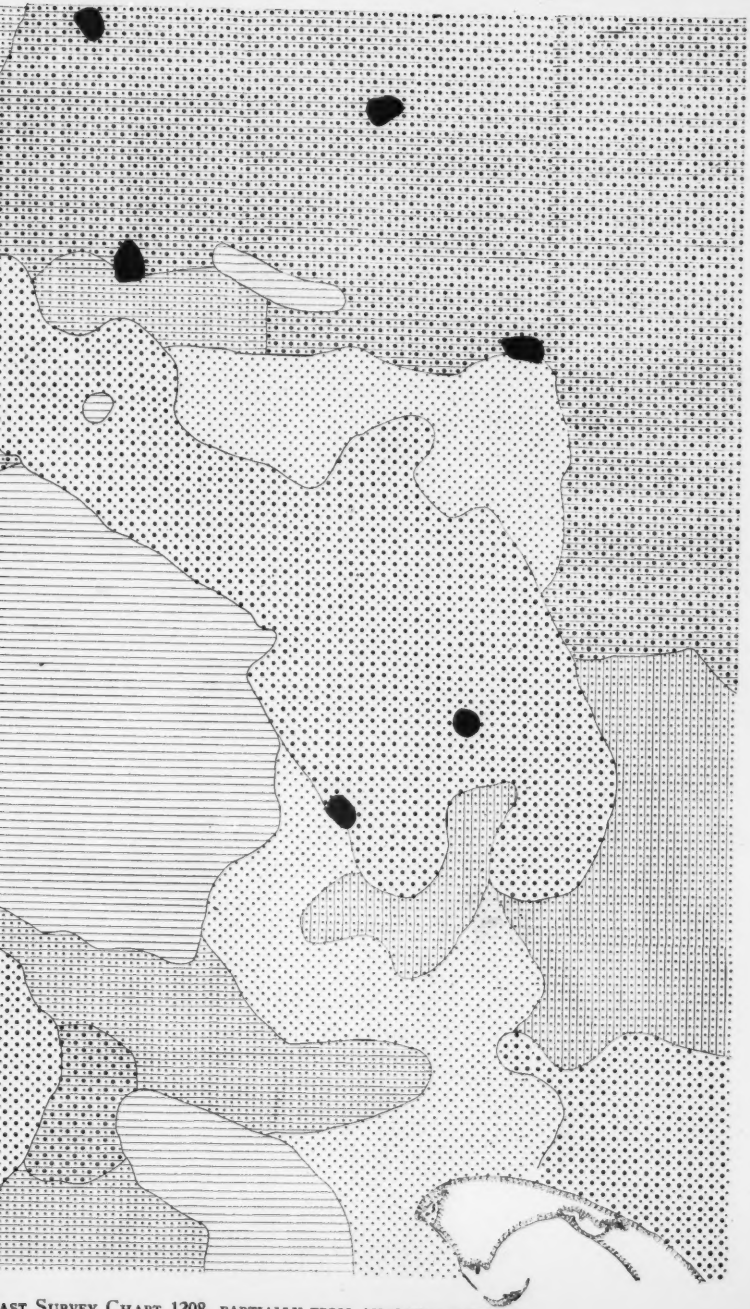

AST SURVEY CHART 1208, PARTIALLY FROM ANALYZED SAMPLES.

series of samples were selected for special study and analyzed by Mr. Max Littlefield in the sedimentation laboratory of the University of Iowa. Although the analytical work was done before the more or less standardized methods now in use had been developed, an attempt was made to determine the significant characters of the samples through mechanical, mineral, and shape analysis.

Partial analyses. After these twenty samples had been run and interpreted in so far as was possible, all the other samples were studied by Shepard under the binocular microscope, resulting in generalized analyses which supplement the more nearly complete analyses of the twenty samples. Portions of the samples were spread out on a piece of cardboard to which were attached sand grains of standard sizes. The sand was then sorted into little piles alongside the grains of standard size to which each was related most closely. Coarser sediment was measured by a scale. The results were not very accurate, but served as a means of telling the relative size of samples taken in a sequence. For example, it was determined in this way whether the sediments grew coarser or finer in going away from the shore and whether the change was constant or reversible.

CHARACTER OF MASSACHUSETTS BAY

The general appearance of the Bay can be observed from the accompanying chart (pl. 1), which has been taken from the U. S. Coast and Geodetic chart after drawing extra contours. The Bay is in the shape of a bow, open to the sea on the east. Cape Cod with its long curving arm forms the southern limit, and Cape Ann the northern limit. The coast line is irregular, having many small estuaries and bays and making a fine coast for yachts and small trading vessels. To the south, a rather low sandy shore along Cape Cod merges into a drumlin coast with greater relief and some sea cliffs, and on the north shore of the Bay, the coast becomes rocky with headlands and islands.

The submarine contours of the Bay show that the bottom is very irregular. There is a deep zone, 15 to 20 miles off shore, with more than 300 feet of water in places. Beyond this is a ridge called Stellwagen Bank, which cuts off the deep from the Gulf of Maine outside. Another and deeper depression, the bottom of which is 594 feet below sea level, lies north of Stellwagen Bank.

DISTRIBUTION OF SEDIMENTS

The number of samples taken does not by itself warrant showing the distribution of the grades of sediment in different parts of the Bay, but taking the collected samples along with the large amount of information supplied by the Coast Survey chart, certain generalized zones can be traced. Since the samples examined by the Coast Survey are only designated as mud, sand, gravel, and pebbles, more exact terms cannot be used for this broad survey. Mud is apparently used for clay and silt, however, and pebbles and gravel are used more or less synony-

mously. Therefore, in the map (pl. 2), the grade terms given are gravel, sand, and silt or clay. These refer roughly to the following scale adapted from Wentworth:[3] Gravel, more than 2 mm.; sand, 2 mm. to 1/16 mm.; silt and clay, less than 1/16 mm.

In general, the sediments run in belts roughly parallel to the coast. As might be expected, sand and gravel occur in the shallow zones near the coast, while in the deeper water, clay and silt form a larger portion of the deposits. One of the features not clearly understood is the zone of rock bottom which separates the coastal fringe of sand and the outer zone of sand and gravel. The recurrence of sand and gravel in the shallow water of Stellwagen Bank out beyond the clay silt zone also needs explanation. Pebbles are found scattered here and there throughout most of the sediments, and rock bottom is also reported in many places.

DESCRIPTION AND INTERPRETATION OF SERIAL SAMPLES

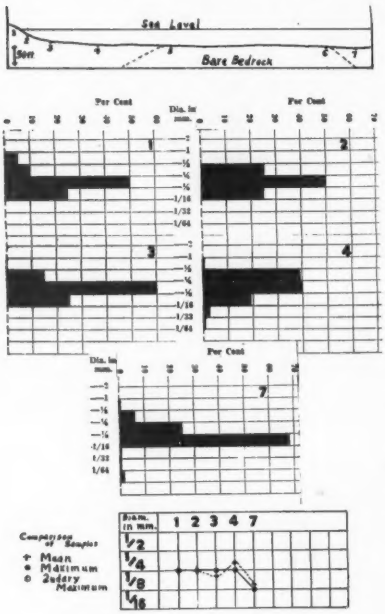

FIG. 1. Profile of the bottom of the bay at Singing Beach, showing positions of soundings and samples of Series I and results of mechanical analyses of samples.

I. SINGING BEACH

CONDITIONS

Singing Beach (see pl. 1) is about a third of a mile long and extends from one cliff to another. The beach consists largely of sand which produces an odd crunching sound when walked on, hence the name. The water deepens from the beach seaward for 400 yards and beyond this for about 800 yards the bottom is irregular and rocky and consists of only slightly submerged reefs.

SAMPLES

The soundings and samples were taken in a line outward from the beach, as shown in Figure 1. Samples 4 (Lab. 02955) and 7 (Lab. 02956) were completely analyzed but the rest were only partially analyzed.

Sizes. Mechanical analyses of samples from Singing Beach are given in Figure 1. Sample 4 from a depth of

[3] Wentworth, C. K., *Jour. Geol.*, vol. 30, p. 381, 1922.

38 feet is coarser than sample 1 from the beach and samples 2 and 3 from depths of 11 and 26 feet, respectively. Sample 7 from outside the area of bare rock is the finest of all and consists of very fine sand with a larger fine sand admixture, a smaller admixture of medium sand and traces of coarse sand, silt and clay. Ninety-eight per cent of the sample is in 3 grades.

Shapes. In this study the shapes of grains were determined and the results are designated according to the method devised by Wentworth.[4] The "shape index" is the ratio of $r1/R$ where $r1$ is the radius of curvature of the sharpest edge as measured by a convexity gauge, and R is the mean diameter of the grain. It is realized that other and perhaps better methods in shape analysis[5] have been devised since the laboratory work was done on these samples. Samples 4 and 7 consist of grains that show little evidence of having been shaped by abrasion. Of all the existing size grades above ¼ mm. in No. 4, the 2-1 mm. and ½-¼ mm. grades have zero indexes, and the 1-½ mm., grade has an index of .135. This last grade in sample 7 has an index of .010.

Minerals. The mineral contents of sample 4 and sample 7 are as follows:

Mineral Analysis of Series I, Sample 4 (02955)

	Per cent	*Per cent*
1 mm.-1/2 mm.		.5
Quartz	35	
Orthoclase	23	
Plagioclase	12	
Shell fragments	15	
Chlorite	12	
1/2 mm.-1/4 mm.		39.1
Quartz	75	
Orthoclase	10	
Plagioclase	7	
Chlorite	4	
Shell fragments		
Hornblende		
Muscovite		
Biotite		
Tourmaline		
Garnet		
1/4 mm.-1/8 mm.		39.4
Quartz	65	
Orthoclase	10	
Plagioclase	10	
Chlorite	8	
Hornblende	3	
1/8 mm.-1/16 mm.		18.6
Quartz	70	
Hornblende	10	
Chlorite	8	
Plagioclase	5	
Orthoclase	3	
Less than 1/16 mm.		2.6
Quartz	85	
Hornblende	10	
Total sample		
Quartz	70.19	
Orthoclase	18.52	
Plagioclase	7.66	
Chlorite	6.25	
Hornblende	3.30	
Shell fragments	.08	

Mineral Analysis of Series, I, Sample 7 (02956)

	Per cent	*Per cent*
1 mm.-1/2 mm.		Trace
Shell fragments		
Quartz		
Plagioclase		
Chlorite		
Muscovite		
1/2 mm.-1/4 mm.		6.1
Quartz	45	
Plagioclase	20	
Chlorite	15	
Shell fragments	10	
Orthoclase	3	

[4] Wentworth, C. K., A method of measuring and plotting the shapes of pebbles, *U. S. Geol. Survey*, Bull. 730, pp. 91-114, 1923.

[5] Trowbridge, A. C., and Mortimore, M. E., Correlation of oil sands by sedimentary analysis, *Econ. Geol.*, vol. 20, pp. 409-423, 1925.

Cox, E. P., A method of assigning numerical and percentage values to the degree of roundness of sand grains, *Jour. Pal.*, vol. 1, pp. 179-183, 1927.

Tester, Allen C., The measurement of the shapes of rock particles, *Jour. Sed. Petrology*, vol. 1, pp. 3-11, 1931.

	Per cent	*Per cent*
Muscovite		
Hornblende		
Garnet		
Epidote		
1/4 mm.-1/8 mm.		24.9
Quartz	70	
Plagioclase	10	
Chlorite	5	
Hornblende	5	
Shell fragments	3	
Muscovite		
Orthoclase		
1/8 mm.-1/16 mm.		67.8
Quartz	80	
Hornblende	8	
Plagioclase	5	
Chlorite	3	
Less than 1/16 mm.		1.2
Quartz	80	
Total sample		
Quartz	75.10	
Plagioclase	7.09	
Hornblende	6.64	
Chlorite	4.17	
Shell fragments	1.36	
Orthoclase	.08	
Undetermined	5.56	

The two samples are similar mineralogically. The minerals differ in order of frequency chiefly because of different textures.

INTERPRETATION

The very small amounts of fine sediment that occur in these samples suggest that the waves and currents are strong enough to carry the smaller particles from the beach more than a half mile out into the Bay but not so strong but that the coarser grades either cannot be carried so far or at least are deposited temporarily on their way into deeper water farther from the beach. The bare rock is probably kept washed clean of sediment at all times. The lack of rounding of the grains and the mineralogical complexity of the sediment indicates that they were derived from glacial drift not far away.

II. WEST BEACH

CONDITIONS

West Beach is located about two miles west of Singing Beach at Lat. 42°33′ and Long. 70°48′ (pl. 1). Eight samples were taken out from a shingle beach into the protected waters of a bay hemmed in by islands. The bottom slopes gently outward, but has some reversal of slope.

SAMPLES

The locations of individual samples are shown approximately in Figure 2. Sample 8 (Lab. 02964) was completely

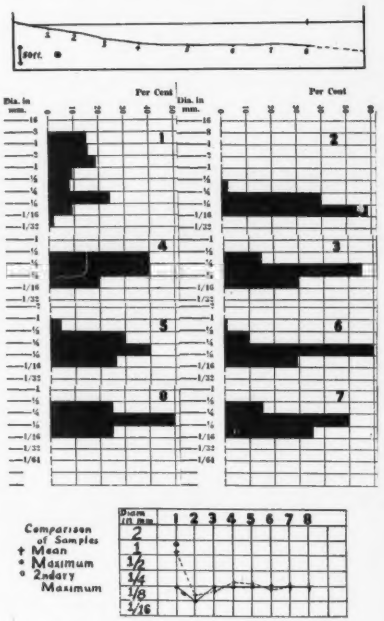

FIG. 2. Profile showing locations of samples of Series II from West Beach and results of mechanical analyses.

analyzed but the other seven were only partially studied.

Sizes. The size grade distributions of the samples are shown in Figure 2. Sample 8 is the coarsest and most poorly sorted of the series and sample 7, taken from only 75 feet farther out, is the finest. There appears to be no particular relation between fineness or degree of sorting and depth or distance from the beach. Sample 8 indicates that the strongest currents are those which run along the beach. This pyramid is typical of sediment deposited by currents of varying competency. The gravel is the maximum load that is carried only when the littoral currents are exceptionally strong. The sand grades were deposited by currents that were able to carry farther the greater part of the silt and all the clay. The whole sample is subject to transportation, the pebbles being rolled along the bottom and the sand grains carried in suspension. The total of the coarser grades is about sixteen times as large as the ¼-⅛ mm. grade, which is considered by Udden[6] to be about the relation of rolled load to suspended load in a current.

Shapes. Excepting the ½-¼ mm. grade, the grains of sample 8 are better rounded than the average and there is little difference in degree of rounding among the different size grades. The indexes of rounding for the several size grades are as follows:

Grades, in mm.:	*8-4*	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
Sample 8 (02964)	.208	.214	.275	.340	.050

[6] Udden, J. A., Mechanical composition of clastic sediments, *Geol. Soc. America Bull.*, vol. 25, p. 676, 1914.

Minerals. The mineral content of sample 8 is indicated as follows:

Mineral Analysis of Series II, Sample 8 (02964)

	Per cent	*Per cent*
8 mm.-4 mm.		15.0
Igneous pebble[a]	100	
4 mm.-2 mm.		15.2
Plagioclase	41	
Igneous pebbles[a]	27	
Quartz	23	
Orthoclase	3	
Hornblende	3	
2 mm.-1 mm.		18.4
Plagioclase	54	
Quartz	24	
Hornblende	9	
Orthoclase	6	
Chlorite	4	
Garnet		
1 mm.-1/2 mm.		9.0
Quartz	42	
Plagioclase	41	
Orthoclase	7	
Chlorite	7	
Hornblende	2	
1/2 mm.-1/4 mm.		8.0
Quartz	55	
Plagioclase	28	
Chlorite	8	
Hornblende	3	
Orthoclase	2	
Garnet		
Epidote		
Zircon		
Muscovite		
1/4 mm.-1/8 mm.		24.0
Quartz	70	
Plagioclase	10	
Chlorite	8	
Hornblende	7	
Orthoclase	1	
Garnet		
Muscovite		
Biotite		
Tourmaline		
Shell fragments		
1/8 mm.-1/16 mm.		9.0
Quartz	80	
Hornblende	10	
Plagioclase	3	
Chlorite	2	

[a] Plagioclose, quartz, and hornblende.

The mineral content of the sand is much the same as that of the pebbles. It is probable that both came from the same glacial drift rather than that the

sand was formed by the wearing down of the pebbles.

III. BEVERLY COVE

CONDITIONS

Beverly Cove is a slight indentation on the north side of Salem Harbor (pl. 1). It is sheltered from violent storm waves by scattered islands and reefs. The water depth scarcely exceeds 45 feet in any part of the bay. The bottom is irregular.

SAMPLES

Two samples were collected and both were completely analyzed. No. 1 (Lab. 02961) was taken in 3 feet of water near the shore and No. 2 (Lab. 02960) in 27 feet of water farther from the shore. They were taken in order to see what changes in sediments there are in a fairly large bay with increasing distance from shore.

Sizes. The mechanical analysis pyramids of the samples are shown in

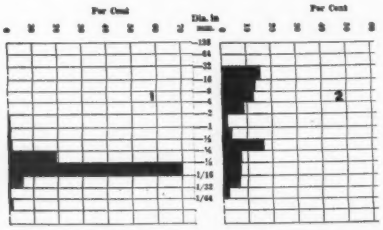

FIG. 3. Mechanical analyses of samples of Series III from Beverly Cove.

Figure 3. Contrary to what might have been expected, No. 1, which is mainly very fine sand, is much finer and better sorted than No. 2 which ranges in size from fine silt to small pebbles.

Shapes. The results of shape analysis are as follows:

Grades, in mm.:	*32-16*	*16-8*	*8-4*	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
(1)						.000	.000
(2)	.027	.013	.066	.126	.192	.318	.000

(1) Ser. III, Sample 1 (02961)
(2) Ser. III, Sample 2 (02960)

In both samples shell fragments and feldspar grains are exceedingly angular but quartz grains are somewhat more rounded. The pebbles of No. 2 show surface evidence of wave rounding. There are no marked differences in shape between the two samples, if differences in texture are considered.

Minerals. The mineral and rock composition of the samples is shown in the following lists:

Mineral Analysis of Series III, Sample 1 (02961)

	Per cent	*Per cent*
1 mm.-1/2 mm.		.4
Quartz	27	
Plagioclase	20	
Shell fragments	18	
Igneous pebbles	13	
Hornblende	10	
Orthoclase	5	
1/2 mm.-1/4 mm.		1.4
Quartz	50	
Plagioclase	20	
Chlorite	10	
Orthoclase	9	
Hornblende	3	
Muscovite	3	
Shell fragments	2	
Augite		
Biotite		
Epidote		
Garnet		
Tourmaline		
Zircon		
Olivine		
Ilmenite		
Magnetite		
Apatite		
Tremolite		
1/4 mm.-1/8 mm.		19.8
Quartz	87	
Chlorite	5	
Plagioclase	3	

	Per cent	*Per cent*
Orthoclase	2	
Hornblende	1	
1/8 mm.-1/16 mm.		68.8
Quartz	80	
Chlorite	7	
Hornblende	5	
Plagioclase	3	
Orthoclase	2	
1/16 mm.-1/64 mm.		8.0
Quartz	85	
Hornblende	10	
Less than 1/64		1.4
Clay	50	
Quartz	40	
Total sample		
Quartz	79.63	
Chlorite	5.79	
Hornblende	4.44	
Plagioclase	2.68	
Orthoclase	1.77	
Clay	.70	
Vegetable matter	.20	
Shell fragments	.02	
Igneous pebbles	.01	

Mineral Analysis of Series III, Sample 2 (02960)

	Per cent	*Per cent*
32 mm.-16 mm.		15.3
Igneous pebbles	100	
16 mm.-8 mm.		13.3
Igneous pebbles	100	
8 mm. 4 mm.		12.7
Igneous pebbles	33	
Quartz	30	
Orthoclase	5	
Schist		
Quartzite		
Basalt		
4 mm.-2 mm.		7.9
Igneous pebbles	45	
Quartz	18	
Plagioclase	12	
Shell fragments	10	
Orthoclase		
Schist		
2 mm.-1 mm.		2.0
Heavy separate	11.4	
Plagioclase	31	
Quartz	27	
Igneous pebbles	20	
Shell fragments	15	
Orthoclase		
Heavy minerals consist of igneous pebbles containing enough augite and hornblende to raise specific gravity above 2.88		
1 mm.-1/2 mm.		3.8
Heavy separate	8.8	
Quartz	45	
Plagioclase	25	
Orthoclase	5	
Shell fragments	3	
Muscovite	2	
Hornblende	2	
Chlorite		
Biotite		
Zircon		
Apatite		
1/2 mm.-1/4 mm.		16.4
Heavy separate	11	
Quartz	60	
Plagioclase	20	
Orthoclase	5	
Muscovite	3	
Chlorite	3	
Hornblende		
Biotite		
Garnet		
Tourmaline		
Zircon		
Rutile		
Magnetite		
Ilmenite		
1/4 mm.-1/8 mm.		7.1
Heavy separate	11	
Quartz	70	
Plagioclase	10	
Muscovite	5	
1/8 mm.-1/16 mm.		7.0
Quartz	80	
Muscovite	10	
Plagioclase	5	
Less than 1/16 mm.		11.2
Quartz	80	
Total sample		
Quartz	36.87	
Igneous pebbles	36.80	
Plagioclase	6.84	
Muscovite	1.63	
Orthoclase	1.62	
Shell fragments	1.20	
Chlorite	.49	
Hornblende	.08	
Organic matter	3.3	

Except that there is more muscovite in the coarser grades in No. 2 than in No. 1 and more in the finer grades in No. 1 than in No. 2, the two samples are similar mineralogically.

INTERPRETATION

Sample 1 appears to be typical beach sand. Most of the fines have been sorted out and deposited elsewhere and

materials coarser than 1 mm. in diameter either were not available at the source or were not transportable to this location by the beach current. Sample 2 contains both maximum and shifting loads. The coarse material is moved only when there are strong waves but the finer material is moved by average waves or tidal currents.

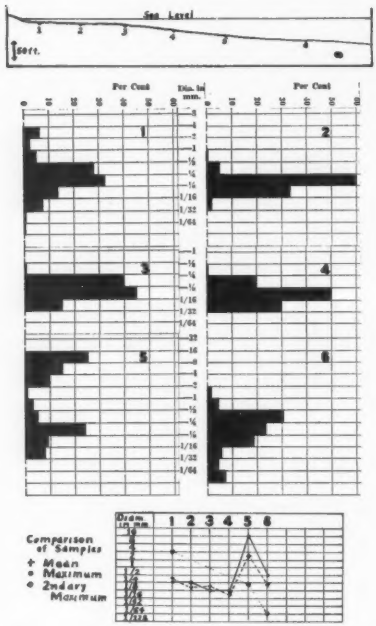

FIG. 4. Diagrams showing locations of samples of Series IV from Mackeral Cove and results of mechanical analyses.

IV. MACKERAL COVE (BEVERLY HARBOR)

CONDITIONS

Mackeral Cove is a sandy beach with a right angled bend in it. Outside at the entrance of Beverly Harbor there is a strong tide which carries water up the Naugus River, a large tidal inlet. There is a channel with steep walls along its sides in the center of the Harbor.

SAMPLES

Six samples were collected at increasing distances and depths from the shores (fig. 4). No. 1 was taken from near the shore and No. 6 from a depth of 21 feet in a channel where there is a strong tide. Samples 1 (02962) and 6 (02963) were completely analyzed but the other four were only partially analyzed.

Sizes. The results of mechanical analysis including a comparison of samples are given in Figure 4.

Rocks and Minerals. The composition of the grains of samples Nos. 1 (Lab. 02962) and 6 (Lab. 02963) are given in the following lists:

Mineral Analysis of Series IV, Sample 1 (02962)

	Per cent	*Per cent*
4 mm.-2 mm.		6.2
Igneous pebbles	88	
Shell fragments	6	
Plagioclase	2	
Quartz	1	
Orthoclase	1	
Muscovite	1	
2 mm.-1 mm.		2.4
Quartz	29	
Shell fragments	19	
Orthoclase	17	
Plagioclase	14	
Hornblende	11	
Muscovite	1	
1 mm.-1/2 mm.		4.9
Quartz	47	
Orthoclase	17	
Plagioclase	14	
Hornblende	7	
Shell fragments	6	
Muscovite		
Chlorite		
1/2 mm.-1/4 mm.		27.6
Quartz	66	
Plagioclase	17	
Hornblende	7	

	Per cent	*Per cent*
Orthoclase	4	
Phlogopite	2	
Chlorite	1	
Muscovite	1	
Shell fragments		
Biotite		
Garnet		
Zircon		
1/4 mm.-1/8 mm.		32.9
Quartz	70	
Orthoclase	8	
Plagioclase	7	
Hornblende	3	
Muscovite		
Phlogopite		
Garnet		
Augite		
Olivine		
Shell fragments		
1/8 mm.-1/16 mm.		13.8
Quartz	70	
Orthoclase	5	
Plagioclase	3	
Hornblende	3	
Muscovite	1	
Phlogopite		
Garnet		
Less than 1/16 mm.		8.3
Quartz	85	
Plagioclase	3	
Orthoclase	3	
Hornblende	3	
Total sample		
Quartz	60.96	
Plagioclase	8.49	
Igneous pebbles	5.45	
Orthoclase	4.98	
Organic matter	3.90	
Hornblende	3.20	
Shell fragments	1.12	
Phlogopite	.55	
Muscovite	.50	
Chlorite	.27	
Undetermined	10.58	

Mineral Analysis of Series IV, Sample 6 (02963)

	Per cent	*Per cent*
2 mm.-1 mm.		1.5
Plagioclase	39	
Quartz	36	
Augite	11	
Igneous pebbles	8	
Orthoclase	6	
Chalcedony		
1 mm.-1/2 mm.		4.4
Quartz	55	
Plagioclase	30	
Orthoclase	6	
Hornblende	5	
Phlogopite		
1/2 mm.-1/4 mm.		30.4
Quartz	70	
Plagioclase	15	
Orthoclase	10	
Hornblende	5	
Phlogopite	2	
Muscovite		
Augite		
Garnet		
Biotite		
Chlorite		
1/4 mm.-1/8 mm.		23.4
Quartz	80	
Hornblende	10	
Plagioclase	5	
Phlogopite	3	
Orthoclase		
Muscovite		
Chlorite		
Augite		
1/8 mm.-1/16 mm.		18.9
Quartz	85	
Hornblende	10	
Plagioclase	2	
Phlogopite	1	
Muscovite		
Augite		
1/16 mm.-1/64 mm.		10.1
Quartz	85	
Hornblende	10	
Less than 1/64 mm.		7.0
Clay	50	
Quartz	40	
Total sample		
Quartz	70.46	
Plagioclase	8.00	
Hornblende	6.98	
Vegetable matter	4.20	
Clay	3.50	
Orthoclase	3.39	
Phlogopite	1.50	
Augite	.17	
Igneous pebbles	.12	

Shapes. The 1-½ mm. grade in sample 1 is more nearly round than in sample 6 but the coarser and finer grades are more angular. The complete results of shape analysis are as follows:

Grades, in mm.:	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
IV-1 (02962)	.130	.127	.266	.020
IV-6 (02963)	.	.181	.233	.062

INTERPRETATION

The reasons for the facts that samples 2, 3, and 4 are better sorted than

1, 5, and 6 and that 5 is the coarsest of the samples are not clear.

Sample 1 probably represents texture and sorting characteristic of shallow water and beach material. The largest particles are small enough to be rolled as the sand is carried in suspension. It is probable that they were derived from beach erosion rather than by transportation from deeper water.

Sample 6 is of a depositional type but it is not probable that all the size grades are deposited at any one time. When the current is strong, the coarser material is rolled and the finer is carried in suspension. As the current slackens, the coarse load stops and progressively finer grains are trapped on the bottom as they change from suspended to saltation or traction load.

The ½-¼ mm. grade is only slightly more rounded in sample 6 than in sample 1 and the difference may be due to greater total distance of transportation in the channel sample.

The most notable fact determined by mineral analysis is that the two samples contain appreciable quantities of phlogopite, a mineral which is not common in the samples from Massachusetts Bay except in those from locations near mouths of rivers. It seems probable that phlogopite is a common mineral in the glacial drift and that the conditions in the bays adjacent to the mouths of streams are favorable for its concentration. The sediments that make up these two samples probably were derived from the same source. The fine grains and the grains of phlogopite of all sizes were probably contributed by a stream but the bulk of the material probably resulted from local beach erosion or was carried from a nearby source by littoral currents.

V. NAUGUS HEAD, SALEM HARBOR

CONDITIONS

Naugus Head is a rocky headland on the south side of the entrance to Salem Harbor. There is a small cove that has a boulder beach to the east of the Head. A mile west of Naugus Head, Salem Harbor ends in a mud flat that is exposed at low tide. The tide flows with a noticeable current across the flat and up the bay toward Naugus Head. The bay is narrow and a river empties into it. Wave action is slight. Two samples were taken at 23 and 26 foot depths respectively.

SAMPLES

Sizes. Pyramids resulting from mechanical analysis are shown in Figure 5. The sediment made up of grains less than 1/64 mm. has considerable range in size and includes considerable colloidal material which was deflocculated only with considerable difficulty. Both samples are poorly sorted.

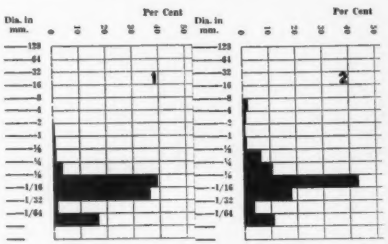

FIG. 5. Pyramids of samples of Series V from Naugus Head, Salem Harbor.

Shapes. The shapes of the grains in the coarser grades of these two samples are as follows:

Grades in mm.:	*8-4*	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
V-1 (02967)			.000	.048	.000
V-2 (02968)	.208	.078	.228	.250	.075

Minerals. The composition of the grains of these samples is shown in the following lists:

Mineral Analysis of Series V, Sample 1 (02968)

	Per cent	*Per cent*
8 mm.-4 mm.		1.6
Plagioclase	100	
4 mm.-2 mm.		1.0
Plagioclase	50	
Chlorite	20	
Hornblende	10	
Slag	10	
Quartz	10	
2 mm.-1 mm.		.4
Plagioclase	33	
Quartz	26	
Chlorite	24	
Orthoclase	5	
Hornblende	3	
Shell fragments	3	
1 mm.-1/2 mm.		1.0
Plagioclase	40	
Quartz	32	
Orthoclase	18	
Chlorite	1	
Hornblende	1	
Shell fragments	1	
1/2 mm.-1/4 mm.		6.6
Quartz	48	
Plagioclase	36	
Hornblende	15	
Plogopite	4	
Orthoclase	3	
Chlorite		
Muscovite		
Shell fragments		
1/4 mm.-1/8 mm.		10.3
Quartz	55	
Plagioclase	18	
Phlogopite	15	
Hornblende	8	
Orthoclase		
Chlorite		
Muscovite		
1/8 mm.-1/16 mm.		43.0
Quartz	50	
Hornblende	20	
Plagioclase	12	
Phlogopite	10	
Orthoclase		
Muscovite		
1/16 mm.-1/64 mm.		21.2
Quartz	60	
Hornblende	25	
Phlogopite	5	
Plagioclase	5	
Less than 1/64 mm.		10.4
Clay	50	
Quartz	40	
Total sample		
Quartz	47.74	
Hornblende	15.18	
Plagioclase	12.06	
Phlogopite	7.17	
Clay	5.20	
Vegetable matter	4.50	
Orthoclase	.40	
Chlorite	.31	
Shell fragments	.02	
Slag	.01	
Undetermined	6.43	

Mineral Analysis of Series V, Sample 2 (02967)

	Per cent	*Per cent*
2 mm.-1 mm.		.3
Shell fragments	90	
Orthoclase	10	
1 mm.-1/2 mm.		.6
Shell fragments	28	
Quartz	24	
Plagioclase	18	
Phlogopite	10	
Hornblende	6	
Orthoclase	4	
Chlorite	4	
1/2 mm.-1/4 mm.		.9
Quartz	50	
Phlogopite	20	
Plagioclase	10	
Chlorite	9	
Hornblende	3	
Orthoclase		
Shell fragments		
1/4 mm.-1/8 mm.		3.2
Quartz	35	
Phlogopite	30	
Plagioclase	15	
Chlorite	10	
Hornblende	3	
Muscovite		
Shell fragments		
Orthoclase		
1/8 mm.-1/64 mm.		76.5
Quartz	80	
Hornblende	8	
Plagioclase	5	
Chlorite	3	
Phlogopite	1	

	Per cent	*Per cent*
Muscovite		
Biotite		
Orthoclase		
Shell fragments		
Less than 1/64 mm.		16.4
Clay	50	
Quartz	40	
Total sample		
Quartz	69.2	
Clay	8.2	
Hornblende	6.26	
Plagioclase	4.48	
Chlorite	2.73	
Phlogopite	1.96	
Organic matter	1.9	
Shell fragments	.44	
Orthoclase	.05	
Undetermined	4.4	

The mineral content of both samples is similar. Both contain a notably large amount of phlogopite. Hornblende is more abundant than feldspar. Chlorite is not so abundant as in other samples.

INTERPRETATION

These samples may be taken as fairly characteristic of the conditions under which they were laid. The poor sorting, the relatively large amount of fine material, including colloidal clay, and the considerable quantities of phlogopite harmonize with the slight effect of wave action. The clay, ultra-clay, and vegetable matter are characteristic of river-borne sediments. There is probably either a hornblende-rich rock or hornblende-rich glacial drift within the drainage area of the stream that flows into the bay. Perhaps chlorite is too weak under river transportation to survive in pieces of super-clay size. These bottom samples differ from those from open beaches in having high clay and phlogopite content and in being less well sorted.

VI. SOUTHEAST BREAKERS

CONDITIONS

The series of rocky shoals that lie oceanward from Bakers Islands are known as the Southeast Breakers (pl. 1). The locality is exposed to fairly violent wave action during wind storms from the east. The shoals prevent westerly winds from producing much effect.

A single sample was taken on the eastern margin of the shoals in water about 20 feet deep. It was hoped especially that it could be determined from the shapes of the pebbles whether they were wave worn or glacially shaped.

SAMPLES

Sizes. The pyramid (fig. 6) shows that the sample consists predominantly

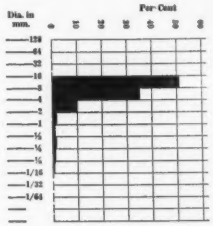

FIG. 6. Pyramid of Series VI, Sample 02965 from Southeast Breakers.

of gravel but contains small percentages of sand of different size grades.

Shapes. The results of shape analysis are as follows:

Grades, in mm.:	*16-8*	*8-4*	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
VI (02965)	.054	.121	.200	.288	.350	.091

The rounding of all size grades is above the average. The surfaces of

pebbles are smooth and pitted with impact moons.

Minerals. The rocks of which the pebbles are made and the mineral composition of the finer grades are given in the following table:

Rock and Mineral Composition of Series VI, Sample 02965 from Southeast Breakers

	Per cent	*Per cent*
16 mm.-8 mm.		50.6
Igneous pebbles	90	
Undetermined rock, probably metamorphic	9	
Gabbro	1	
8 mm.-4 mm.		35.2
Igneous pebbles	56.6	
Undetermined metamorphic, same as in 16-8	15	
Feldspathic	10	
Chloritic diorite	9	
Chloritic diorite, containing quartz	7	
Plagioclase	2.4	
4 mm.-2 mm.		9.7
Igneous pebbles	27.7	
Undetermined metamorphic	17	
Chloritic diorite	15	
Chloritic diorite, containing quartz	14	
Feldspathic	7	
Gneiss	2	
Quartzite	1	
Quartz	11.4	
Plagioclase	5.9	
2 mm.-1 mm.		1.6
Plagioclase	40	
Quartz	25	
Chlorite	25	
Orthoclase	5	
Hornblende	5	
1 mm.-1/2 mm.		.8
Quartz	40	
Plagioclase	33	
Chlorite	24	
Hornblende	1	
1/2 mm.-1/4 mm.		1.4
Quartz	70	
Plagioclase	15	
Chlorite	10	
Hornblende		
Muscovite		
1/4 mm.-1/8 mm.		.5
Quartz	65	
Plagioclase	10	
Chlorite	10	
Hornblende	10	
Muscovite		
1/8 mm.-1/16 mm.		.2
Quartz	85	
Hornblende	10	
Plagioclase	3	
Total sample		
Igneous and metamorphic pebbles	93.01	
Quartz	3.29	
Plagioclase	2.59	
Chlorite	.78	
Hornblende	.16	
Orthoclase	.08	

INTERPRETATION

The gravel is moved only under exceptional conditions and the finer material represents shifting load that is transported under normal conditions and has been merely trapped by the gravel. Storm waves are probably responsible for the sorting.

It is not possible to determine with certainty whether the largest pieces were first glacially shaped or were merely fragmental. The general shapes may not have been greatly changed but any sharp corners and edges they may have had have been rounded off and the surfaces have been smoothed and pitted by wave action.

The abundance of one kind of rock termed "undetermined metamorphics" suggests an outcrop nearby, but this rock may have become a part of the glacial drift before having been reworked by waves. The sand probably came from the drift and was not so locally derived.

VII. MARBLEHEAD NECK (GREAT HEAD)

CONDITIONS

The east side of Marblehead Neck is well exposed to storm waves, espe-

cially from the occasional "southeasters." During a storm the waves break all over the 30- or 40-foot cliffs which are found along the shore. The "Churn," a place where a dike has been cut away by wave erosion, causing a trench into which waves rush with violence and cause spray to be thrown high in the air, is a well-known show place for visitors. Between the cliffs just south of Great Head (known locally as Castle Rock) there is a stretch of beach extending a few hundred yards to the south. The beach is shifted and changed from time to

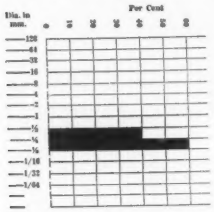

FIG. 7. Pyramid of sample of Series VII from off the "Churn," Marblehead Neck.

time during storms so that a description of it is only correct temporarily. It is made up of fairly coarse pebbles ranging up to a foot in diameter. The samples which were taken off Great Head and seaward from the beach were only partially studied and none of them were subjected to complete laboratory analysis. No shape or mineral analysis was made.

SAMPLES

Sizes. A sample taken from 15 feet of water 50 feet from the shore off the "Churn" has a size grade distribution as shown in Figure 7. A series of soundings and samples were taken southwest of Castle Rock, the arrangement and mechanical analysis of which are shown in Figure 8. Locations and

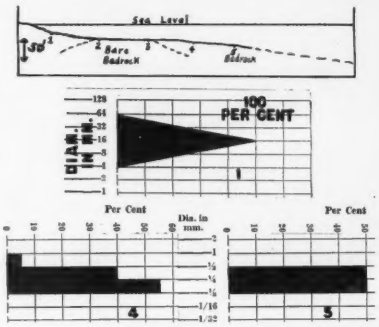

FIG. 8. Diagram showing soundings and samples and pyramids of samples of Series VII from off Castle Rock, Marblehead Neck. The pyramid for No. 1 indicates that grains between 64 and 4 mm. make up the whole of the sample.

pyramids of three samples taken 3 to 7 miles southeast from Castle Rock and comparison of the eight samples are shown in Figure 9.

INTERPRETATION

These samples show a contrast between sand that borders cliffs (fig. 7) and gravel off of pebble beaches that are next to cliffs (fig. 8). Farther out there is rock bottom and well out from shore there are sand, silt and perhaps clay. The conclusions reached are as follows: (1) The coarse material from cliffs is carried to one side by the along-shore currents. (2) There is a zone some distance from shore where waves are effective in scouring

the bottom. Near shore there is too much débris being brought in for wave erosion to keep pace. (3) Beyond this zone sediment is deposited in deeper water, say 100 feet deep. (4) The dividing line between sand and silt-clay deposition is at a depth of about 130 feet. (5) The clay deposition since the glacial period has been very slow as shown by the presence of glaciated pebbles mixed in the clay.

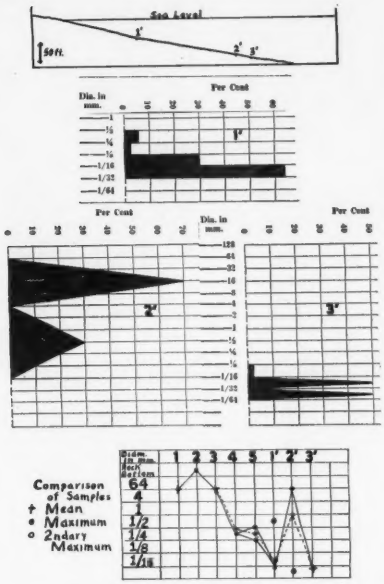

FIG. 9. Diagrams showing locations and pyramids of samples from southeast of Castle Rock and comparison of all samples of Series VII from near Castle Rock, Marblehead Neck. The pyramid for No. 2' indicates that grains between 64 and 4 mm. make up 70 per cent and grains between 4 mm. and 1/16 mm., 30 per cent of the sample.

VIII. THE CAUSEWAY (MARBLEHEAD BEACH)

CONDITIONS

The Causeway is a tombolo connecting a former island to the mainland at Marblehead. It has recently been built up artificially to make a road out to Marblehead Neck. There is a stretch of some 10 miles south and southwest of this beach where the water is open except for a few reefs. The southwest winds which blow almost constantly in summer cause small waves to break along the westerly side of the bar most of the time, but storm waves greater than three feet in height are rare. The bottom is irregular and not well graded.

SAMPLES

Samples 1 and 2 were taken at the same elevation above sea level but No. 1 came from a small ridge at right angles to the beach and No. 2 from a bordering hollow. Samples 3 to 7 inclusive were taken at increasing distances from the beach and at increasing water depths (fig. 10). None of these samples were studied in detail in the laboratory.

The results of partial mechanical analysis of the samples and a comparison of the samples are shown in Figure 10. Sample 5 is missing but the collector's notebook indicates that this sample was finer than sample 4.

INTERPRETATION

This series is characteristic, so far as mechanical composition is concerned, in that there is an increase in fineness out a short distance from the

exposed beach and then a change from coarse to fine.

IX. LYNN BEACH

CONDITIONS

Lynn Beach is another example of a tombolo. The exposed side of the tombolo is to the east, where Nahant Bay offers very little protection from south-

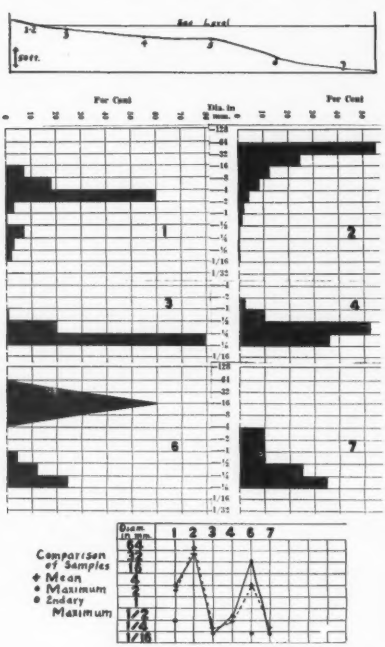

FIG. 10. Diagrams showing locations and pyramids of samples and comparisons of samples of Series VIII from the Causeway, Marblehead Beach.

east storms. The water deepens about 25 feet per mile for the first three miles and presents a fairly well graded slope. The beach is mostly sandy although it contains bands of pebbles above the usual high-tide level.

SAMPLES

Seven samples were collected between a point at high-tide level on the beach and a point about 2 miles off shore where the water was 45 feet deep (fig. 11).

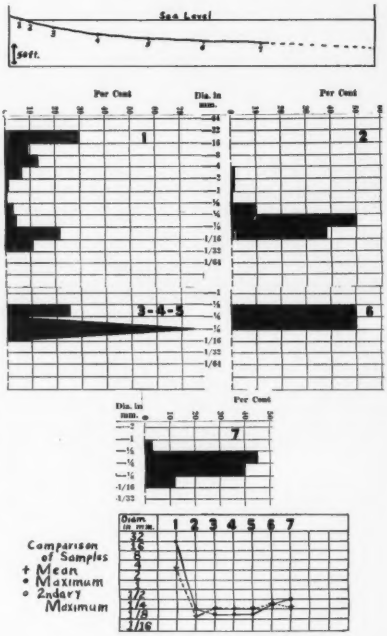

FIG. 11. Diagrams showing locations and results of partial mechanical analyses of samples of series IX from Lynn Beach.

The results of partial mechanical analysis of the samples are shown in Figure 11. The series shows a variation from coarse on shore to fine out a short distance, approximately uni-

form fineness for a distance farther, and a slight increase in coarseness near the outer edge of the bay.

X. REVERE BEACH

CONDITIONS

Revere Beach is a spit which extends in a northeasterly direction nearly across a bay. The bay has since been mostly filled in by the streams coming into it, by the vegetation, and by artificial dumping. The Beach is now the site of a large pleasure resort. The fine sand makes it an excellent bathing beach. The waves coming into Broad Sound, which extends out from the beach, are very much reduced in force and are rarely more than a foot high. Off the east side of Nahant, the point of land bordering the bay on the east, the waves are large and come against the coast from fairly deep water so that they have great erosive force.

SAMPLES

Ten samples were collected from positions as indicated in Figure 12. Four of the samples, No. 1 (Lab. 02954), No. 4 (02953), No. 5 (02952) and No. 8 (02951) were completely analyzed and the remainder were studied partly only.

Sizes. The size-grade distribution for each of the ten samples and a comparison of all ten are shown in Figure 12. All samples but No. 4 are well sorted. In general, the samples from near shore are muds and those from farther out are gravels; in this case the samples increase in coarseness with increasing distance from shore.

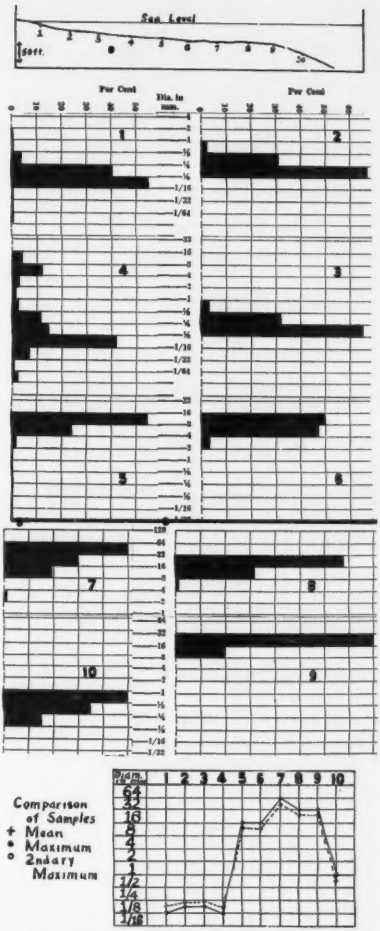

FIG. 12. Diagrams showing the location and texture of Series X, Samples 1-10 from Revere Beach.

Shapes. Results of shape analyses are as follows:

Grades, in mm.:	*32-16*	*16-8*	*8-4*
X-1 (02954)			
X-4 (02953)			.121
X-5 (02952)		.000	.066
X-8 (02951)	.003	.000	.005

Grades, in mm.:	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
X-1 (02954)		.282	.209	.135
X-4 (02953)	.153	.307	.244	.156
X-5 (02952)	.133		.000	
X-8 (02951)				

The pebbles show surface indications of having been rounded by waves and the sand grains are rather more rounded than the average.

Minerals and Rocks. The rock and mineral characters of the constituent pebbles and grains of the four samples that were completely analyzed are indicated in the following lists:

Rock and Mineral Analysis of Series IX, Sample 1 (02954)

	Per cent	*Per cent*
2 mm.-1 mm.		.1
Igneous pebbles	60	
Quartz	20	
Shell fragments	20	
1 mm.-1/2 mm.		.2
Quartz	50	
Plagioclase	24	
Chlorite	9	
Shell fragments	8	
Orthoclase	3	
Biotite	1	
Hornblende	1	
1/2 mm.-1/4 mm.		3.6
Quartz	70	
Plagioclase	13	
Chlorite	9	
Orthoclase	3	
Hornblende	1	
Muscovite	1	
Biotite		
Shell fragments		
Zircon		
1/4 mm.-1/8 mm.		40.1
Quartz	70	
Chlorite	10	
Plagioclase	5	
Hornblende	3	
Garnet		
Muscovite		
Orthoclase		
Tourmaline		
Epidote		
1/8 mm.-1/16 mm.		54.7
Quartz	75	
Chlorite	12	
Hornblende	5	
Plagioclase	3	
Less than 1/16 mm.		.8
Quartz	80	
Chlorite	5	

	Per cent	*Per cent*
Total samples		
Quartz	72.27	
Chlorite	10.96	
Plagioclase	4.18	
Hornblende	3.96	
Orthoclase	.11	
Igneous pebbles	.06	
Shell fragments	.04	
Muscovite	.04	
Biotite	.01	
Undetermined	8.37	

Rock and Mineral Analysis of Series IX, Sample 4 (02953)

	Per cent	*Per cent*
16 mm.-8 mm.		3.8
Shell fragments	100	
8 mm.-4 mm.		11.8
Igneous pebbles	100	
4 mm.-2 mm.		2.6
Plagioclase	43	
Hornblende	43	
Igneous pebbles	4	
2 mm.-1 mm.		1.6
Quartz	55	
Hornblende in crystal aggregates partially or wholly altered to chlorite	35	
Hornblende	5	
Plagioclase	5	
1 mm.-1/2 mm.		2.2
Quartz	53	
Chlorite	21	
Plagioclase	19	
Shell fragments	1	
1/2 mm.-1/4 mm.		11.6
Quartz	65	
Chlorite	18	
Plagioclase	12	
Hornblende		
Orthoclase		
Muscovite		
Biotite		
Shell fragments		
Garnet		
1/4 mm.-1/8 mm.		14.6
Quartz	80	
Chlorite	16	
Plagioclase	2	
Hornblende		
Orthoclase		
Shell fragments		
Tourmaline		
Epidote		
Garnet		
1/8 mm.-1/16 mm.		41.8
Quartz	80	
Chlorite	10	
Plagioclase	5	

	Per cent	Per cent
Hornblende	2	
Tourmaline		
Muscovite		
Biotite		
Shell fragments		
Less than 1/16 mm.		9.8
Quartz	75	
Hornblende	15	
Total Sample		
Quartz	62.0	
Igneous pebbles	11.9	
Chlorite	9.6	
Plagioclase	5.4	
Shell fragments	3.8	
Hornblende	3.5	
Undetermined	3.8	

Rock and Mineral Analysis of Series IX, Sample 5 (02952)

	No.	Per cent	Per cent
16 mm.-8 mm.			74.4
Igneous and metamorphic pebbles		100	
Gabbro diorite, containing hornblende and black augite	5		
Slates	3		
Quartzose	3		
Breccia	2		
Phorphyry	1		
Feldspathic	1		
Gneiss	1		
8 mm.-4 mm.			23.6
Igneous and metamorphic pebbles		87	
Diorite containing hornblende partially or wholly altered to chlorite	7		
Quartzose	7		
Feldspathic	3		
Slate	3		
Breccia	3		
Slag	2		
Plagioclase		10	
Quartz		3	
4 mm.-2 mm.			1.7
Igneous and metamorphic pebbles		74	
Chloritic diorite	5		
Breccia	2		
Slag	2		
Quartzose	1		
Slate	1		
Quartz		13	
Plagioclase		13	
1/2 mm.-1/4 mm.			.1
Quartz		75	
Chlorite		10	
Plagioclase		8	
Hornblende		3	
Garnet			
Shell fragments			
1/8 mm.-1/16 mm.			.2
Quartz		85	
Chlorite		10	
Total sample			
Igneous and metamorphic pebbles		96.01	
Plagioclase		2.59	
Quartz		1.18	
Chlorite		.03	

Rock and Mineral Analysis of Series IX, Sample 8 (02951)

	No.	Per cent	Per cent
32 mm.-16 mm.			67.4
Igneous and metamorphic pebbles		100	
Unknown metamorphic	1		
Quartzite	1		
16 mm.-8 mm.			31.7
Igneous and metamorphic pebbles		100	
Chlorite diorite	4		
Slate	1		
Unknown metamorphic	1		
8 mm.-4 mm.			.9
Igneous pebbles		100	
Chlorite diorite (with quartz)	1		
Total sample			
Igneous and metamorphic pebbles		100	

INTERPRETATION

The material grades from fine to coarse and back to fine. Probably the chief source of the outer sediments is the cliff shore of Nahant to the east. The pebbles resemble the rock found in these cliffs. The material is apparently washed into the deep water of the Bay and the fines are carried both shoreward and out to sea according to the type of current which is acting on the mass. Perhaps during storms material is washed shoreward and during ground swells the returning water carries it seaward.

XI. NANTASKET BEACH

CONDITIONS

Nantasket Beach has the appearance of a spit but is actually a tombolo as it connects some of the drumlins of Boston Harbor to the mainland. Except

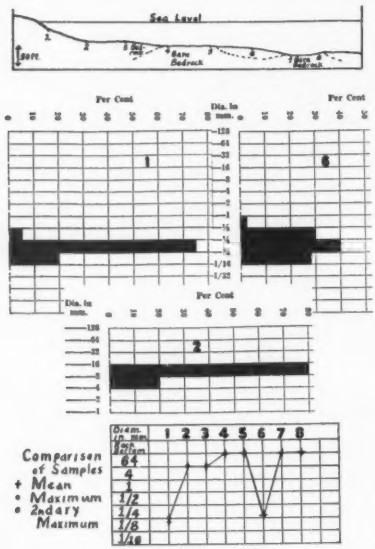

FIG. 13. Diagrams showing locations of soundings and samples and results of mechanical analyses of samples of Series XI from Nantasket Beach.

for a few small reefs, there is an open stretch of water for a long distance to the eastward, so the easterly storms cause fairly large waves to break on the beach and on the adjacent drumlin hills and rock cliffs to the south. The water deepens rather irregularly off the coast. Probably a ridge of rock runs parallel to the coast about a mile and a half from shore. This comes to the surface in Harding ledge.

SAMPLES

Samples and soundings were taken as shown in Figure 13. The samples were not studied in detail.

The results of analysis of the three samples are shown in Figure 13. Sample 1 is mainly fine mud and sand and sample 2 is gravel. Sample 6, which came from a pocket of sediment with bare bedrock on either side, consists entirely of sand which is, however, not well sorted.

XII. WOOD END, CAPE COD

CONDITIONS

The general conditions on Cape Cod are given in Plate 1 and Figure 14. At the end of the Cape the tide may have had a great influence upon the coastal configuration. A strong current curves around the end of the cape in the flood. It runs up to 4 knots an hour, which is fast enough to cause very important transportation of sand. The end of the cape is growing rapidly. In the summer of 1931 measurement by Shepard showed that it had been extended about 525 feet beyond its position in 1921.

The bottom topography is puzzling, since there is a trench of deep water extending along the outside of the arm of the cape, around the end, and even on the inside for a short distance (pl. 1; fig. 14). Sample 1 (02958) was taken from this trench. Bordering the land there is a narrow shelf with shallow water. Sample 2 (02959) was taken from this shelf. Beyond this a steep slope extends down to the trench. The angle of this slope was measured

by taking soundings from both ends of a row boat. In one case an inclination of 46° was obtained in this way. Several other measurements showed slopes as high as 40°. Such slopes are certainly unusual for sand, even under water.

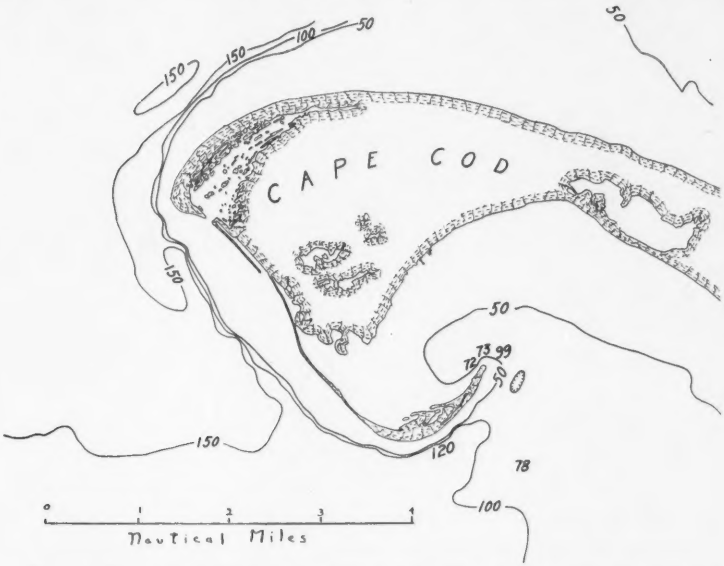

FIG. 14. Sketch map showing the bottom topography near the end of Cape Cod. The Cape is practically surrounded by a depression. Source, U. S. Coast Survey Chart 341.

SAMPLES

Sizes. The results of mechanical analysis of the two samples are shown in Figure 15. Both are poorly sorted and No. 2 is coarser than No. 1.

Shapes. The shapes of grains in the coarser size grades of the samples of this series are indicated as follows:

Grades in mm.:	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
XII-1 (02958)		.000	.000	.000
XII-2 (02959)	.217	.171	.141	.099

The grains in the coarser grades of Sample 1 are angular and the grains of No. 2 are less well rounded than the average. Examination of the finer

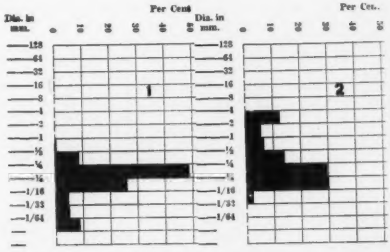

FIG. 15. Pyramids of samples Series XII from Wood End, Cape Cod.

grades of both samples indicates no more than the normal number of well

rounded grains that may be wind-shaped.

Minerals. The results of mineral analysis of these two samples are presented in the following lists:

Mineral Analysis of Series XII, Sample 1 (02958)

	Per cent	Per cent
1 mm.-1/2 mm.		.1
Muscovite	99	
Chlorite	1	
1/2 mm.-1/4 mm.		8.5
Quartz	85	
Muscovite	5	
Chlorite	3	
Plagioclase	1	
Hornblende		
Biotite		
1/4 mm.-1/8 mm.		48.3
Quartz	90	
Chlorite	5	
Muscovite	1	
Hornblende		
Plagioclase		
Tourmaline		
1/8 mm.-1/16 mm.		26.0
Quartz	80	
Chlorite	5	
Plagioclase	1	
Hornblende	3	
Muscovite		
Phlogopite		
Tourmaline		
1/16 mm.-1/64 mm.		8.7
Quartz	85	
Hornblende	5	
Chlorite	5	
Less than 1/64		8.4
Clay	50	
Quartz	40	
Total Sample		
Quartz	82.31	
Chlorite	4.45	
Clay	4.20	
Hornblende	1.21	
Muscovite	1.01	
Plagioclase	.35	
Undetermined	6.47	

Mineral Analysis of Series XII, Sample 2 (02959)

	Per cent	Per cent
4 mm.-2 mm.		12.6
Quartz	66	
Shell fragments	34	
2 mm.-1 mm.		5.7
Shell fragments	65	
Quartz	33	
Orthoclase	1	
1 mm.-1/2 mm.		6.1
Quartz	62	
Shell fragments	33	
Orthoclase	2	
Chlorite	1	
1/2 mm.-1/4 mm.		13.9
Quartz	75	
Chlorite	12	
Orthoclase	5	
Plagioclase	3	
Shell fragments	3	
Hornblende	1	
Biotite		
Augite		
1/4 mm.-1/8 mm.		29.3
Quartz	75	
Chlorite	8	
Plagioclase	5	
Hornblende	5	
Orthoclase	3	
1/8 mm.-1/16 mm.		29.9
Quartz	80	
Hornblende	8	
Plagioclase	5	
Orthoclase	3	
Chlorite	2	
Less than 1/16 mm.		2.5
Quartz	85	
Hornblende	10	
Total Sample		
Quartz	72.30	
Shell fragments	10.41	
Chlorite	4.67	
Hornblende	4.23	
Plagioclase	3.35	
Orthoclase	2.65	
Undetermined	2.49	

INTERPRETATION

It does not appear from the evidence at hand that sample 1 or the finer grades of No. 2 are primarily wind-blown. It may well be that some of the grains were contributed by the wind but the usual characters of wind-blown sands have been obliterated by current action which determines the textural and mineral content.

XIII. HIGHLAND LIGHT, CAPE COD

CONDITIONS

Highland Light is situated on the outside of Cape Cod (pl. 1). The waves are almost always larger here

than in Massachusetts Bay because the presence of Stellwagen Bank breaks the force of the waves coming into the Bay, while off the Cape there is an open stretch of deep water. The land here is made up of unconsolidated deposits which are being eroded back several feet a year. Davis[7] has estimated that two miles of the Cape have been cut away since glacial times. The well graded sea-bottom off the Cape is in contrast to the irregularities so common off points within Massachusetts Bay. The even slope off the Cape is a great aid in navigation as it makes it possible for a navigator to determine a line of position in a heavy fog.

SAMPLES

Five samples were collected between a point one-half mile offshore in 40 feet of water and a point two and one-half miles offshore in 145 feet of water (fig. 16). Only partial analysis was made of these samples.

The results of incomplete mechanical analysis of these samples are shown in Figure 16. There appears to be no regularity in variation in coarseness. Nos. 2 and 3 have considerable textural range indicating poor sorting.

Both the gravel and the sand consist mostly of quartz but there are also minor quantities of mica. The materials were probably derived from Cape Cod.

XIV. STELLWAGEN BANK

CONDITIONS

Stellwagen Bank extends north of Cape Cod for at least 20 miles, but is separated from the Cape by a deep water channel. The bank is remarkably uniform on top. It has one mesa-like hill at its southwestern extremity,

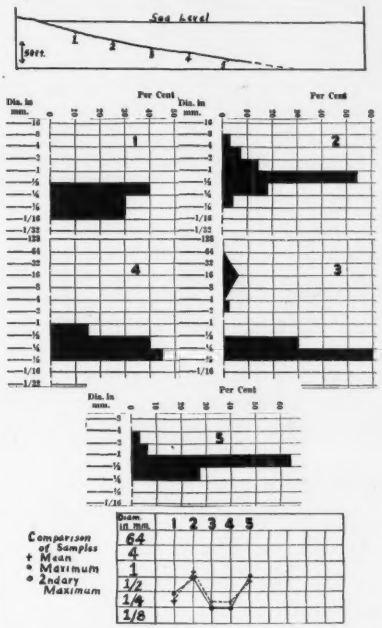

FIG. 16. Diagrams showing locations and results of mechanical analyses of samples of Series XIII offshore from Highland Light, Cape Cod.

where the water is only about 57 feet deep. The rest of the bank is about 87 feet below mean low tide. The water deepens very gradually toward the north (*pl. 1 and fig. 19*).

SAMPLES

A number of samples were taken but only two were studied. No. 1 (*02970*) came from the central part of the bank where the water is 80 feet

[7] Davis, W. M., The outlines of Cape Cod, *Am. Acad. Arts and Sci., Proc.*, vol. 31, pp. 303-332.

deep and No. 2 (02969) from the south end of the bank where the water is 70 feet deep.

Sizes. The results of mechanical analysis of the two samples are indicated in Figure 17. No. 1 is not so

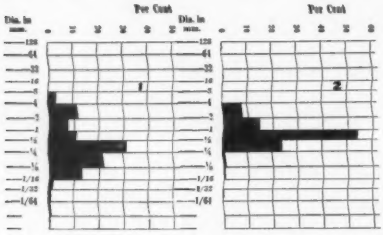

FIG. 17. Pyramids of samples of Series XIV from Stellwagen Bank.

well sorted and not quite so coarse as No. 2.

Shapes. No. 1 (02970) has the best rounded 2-1 mm. and ½-¼ mm. grades of all the samples studied and the mineral grains in the 4-2 mm. grade are also well rounded. Even the shell fragments show rounded edges. No. 2 is just below the average in roundness except in the ½-¼ mm. grade which has more roundness than the same grade of No. 1. Complete results of shape analysis are as follows:

Grades, in mm.:	*8-4*	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
XIV-1 (02970)		.133	.371	.350	.242
XIV-2 (02969)	.000	.165	.200	.131	.100

Minerals. The results of mineral analysis are shown in the following lists:

Mineral Analysis of Series XIV, Sample 1 (02970)

	Per cent	*Per cent*
4 mm.-2 mm.		7.2
Shell fragments	50	
Quartz	33	
Hornblende	17	
2 mm.-1 mm.		14.5
Quartz	90	
Shell fragments	6	
Plagioclase	1	
Hornblende	1	
1 mm.-1/2 mm.		53.9
Quartz	95	
Hornblende	1	
Plagioclase		
Epidote		
Phlogopite		
1/2 mm.-1/4 mm.		23.8
Quartz	95	
Hornblende	1	
Plagioclase		
Epidote		
Garnet		
1/4 mm.-1/8 mm.		.5
Quartz	90	
Hornblende	5	
Chlorite		
Epidote		
Garnet		
Zircon		
1/8 mm.-1/16 mm.		.1
Quartz	90	
Hornblende	5	
Total Sample		
Quartz	89.52	
Shell fragments	3.38	
Hornblende	2.18	
Plagioclase	.15	
Undetermined	4.77	

Mineral Analysis of Series XIV, Sample 2 (02969)

	Per cent	*Per cent*
8 mm.-4 mm.		3.0
Shell fragments	100	
4 mm.-2 mm.		11.4
Shell fragments	60	
Quartz	20	
Plagioclase	13	
2 mm.-1 mm.		7.0
Quartz	58	
Shell fragments	13	
Plagioclase	3	
Muscovite	1	
1 mm.-1/2 mm.		10.9
Quartz	95	
Shell fragments		
Chlorite		
Plagioclase		
Orthoclase		
Muscovite		
1/2 mm.-1/4 mm.		31.2
Quartz	93	
Chlorite	1	
Muscovite		

Orthoclase		
Hornblende		
Plagioclase		
Garnet		
Shell fragments		
1/4 mm.-1/8 mm.		21.5
Quartz	90	
Chlorite	3	
Shell fragments		
Hornblende		
Orthoclase		
Plagioclase		
Muscovite		
Biotite		
Tourmaline		
1/8 mm.-1/16 mm.		12.8
Quartz	85	
Hornblende	5	
Chlorite		
Muscovite		
Less than 1/16 mm.		2.2
Quartz	85	
Hornblende	7	
Total Sample		
Quartz	77.60	
Shell fragments	10.76	
Plagioclase	1.69	
Chlorite	.96	
Hornblende	.79	
Muscovite	.07	
Undetermined	7.73	

Both samples are high in quartz. No. 2 contains some chlorite.

INTERPRETATION

The evidence of the samples has little bearing on the question of the origin of Stellwagen Bank, for the original material of the Bank must be covered by a layer, perhaps thin, of sediment which has been reworked by waves and currents and is made up of the present maximum and shifting loads. If the bank were a glacio-fluvial deposit now suffering submarine erosion, the materials at its surface would probably be much the same as if they had been brought out by currents from the glacio-fluvial material of Cape Cod. Sample 1 was taken at a considerable distance from the Cape and it seems unlikely that material would be carried so far in this direction.

AVERAGE ANALYSES

Sizes. A composite histogram made up by averaging the percentages of the different size grades for the whole of the 64 samples mechanically analyzed

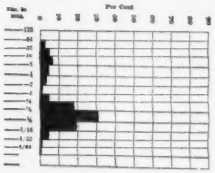

FIG. 18. A composite pyramid of the 64 pyramids of previous figures.

is shown in Figure 18. This does not indicate the mechanical composition of the average sample, for no sample of any of the fourteen series approaches this in mechanical composition. It merely indicates that the samples as a whole range in size of grains from clay to pebbles, that the ¼-⅛ mm. grade (fine sand) is the most abundant on the average in the samples, that the ⅛-1/16 mm. (very fine sand) and ½-¼ mm. (medium sand) grades on either side of the most abundant grade occur in approximately equal proportions, and that the coarse admixtures are more than four times as abundant as the fine admixtures. That is, these samples on the average are sands and gravels and not sands, silts, and clays.

General conclusions drawn from the

mechanical analyses follow: (1) Fine silt and clay tend to be carried clear off the Continental Shelf. Only four samples contain more than 8% of clay and three of these are in bays adjacent to river mouths. The fourth, from west of Cape Cod [Series XII, Sample 1 (02958)], contains clay probably in transport under maximum conditions. There are parts of the bay which are noted as mud on the Coast Survey Chart but there are no samples from these localities. As there are no soundings recording a depth greater than 318 feet, it seems possible that waves during storms may pick up mud from any part of the bay as it is generally accepted that strong waves may pick up clay at a depth of 500 feet. The presence of clay in small percentages in many of the samples is evidence of its continual transport as small amounts may be trapped with the coarser grades. (2) The presence of two maxima in many of the pyramids and the "double" type of pyramid which is strongly developed in the deeper water samples [Series III, sample 2 (02960)] are indicative of two loads, carried under different conditions. It is inconceivable that all grades of material could be transported and deposited at the same time. It seems probable that the coarser part of the sediment represents load carried when the transporting power is at its maximum, for instance in time of storm. Between storms the transporting power is less and the finer material is left on the surface of deposition. It is probable that this load varies from hour to hour but in general it may be thought of as the average load of normal conditions. If this temporarily deposited material is thin the sampler may penetrate through to the coarser material below. The proportion of shifting load to maximum load may thus be significant in interpreting the amount of deposition in a given time.

Shapes. By averaging the shape indexes for all the size grades for all the samples of which shape analyses were made the following shape analysis is made up

Grades, in mm.:	*32-16*	*16-8*	*8-4*
Average Sample	.015	.011	.107

Grades, in mm.:	*4-2*	*2-1*	*1-1/2*	*1/2-1/4*
Average Sample	.175	.202	.178	.060

These samples are, on the whole, very angular, partly because of the larger amount of shells, micas, feldspars, etc., which are normally angular, and partly because of slight abrasional angularity of the mineral grains. Those containing the highest percentages of quartz are the most rounded because less resistant angular grains have been destroyed and because shape and specific gravity sorting have removed other angular and heavy minerals. So it seems that the roundness is indicative of transportation.

The 2-1 mm. grade is the best rounded. The grade 1/8-1/16 mm., supposedly below the limit of rounding in water, shows a few well rounded grains which were probably shaped by wind. It does not follow that this is positive evidence of recent wind-rounding for such rounded grains may be found in the same grade of almost any sediment. None of the samples contains enough of these grains to im-

ply recent wind-rounding although some of the samples contain grains which have slightly frosted surfaces.

Minerals. An average of the mineral analyses of all the completely analyzed samples is as follows:

Average Mineral Analysis

	Per cent	*Per cent*
32 mm.-16 mm.		4.35
Igneous and metamorphic pebbles	100	
16 mm.-8 mm.		9.17
Igneous and metamorphic pebbles	66	
Shell fragments	34	
8 mm.-4 mm.		5.46
Igneous and metamorphic pebbles	61	
Shell fragments	23	
Plagioclase	12	
Quartz	3	
Orthoclase	.5	
4 mm.-2 mm.		3.98
Igneous and metamorphic pebbles	40	
Quartz	19	
Plagioclase	17	
Shell fragments	15	
Hornblende	5	
Chlorite	2	
Slag	1	
Orthoclase	.4	
Muscovite	.1	
2 mm.-1 mm.		2.94
Quartz	36	
Shell fragments	20	
Plagioclase	18	
Igneous pebbles	10	
Chlorite	8	
Orthoclase	4	
Hornblende	3	
Augite	1	
Muscovite	.2	
1 mm.-1/2 mm.		5.25
Quartz	49	
Plagioclase	20	
Shell fragments	8	
Orthoclase	7	
Muscovite	7	
Chlorite	6	
Hornblende	2	
Phlogopite	.7	
Biotite	.2	
1/2 mm.-1/4 mm.		12.26
Quartz	71	
Plagioclase	14	
Chlorite	6	
Orthoclase	3	
Hornblende	3	
Phlogopite	2	
Muscovite	.8	
Shell fragments	.5	
1/4 mm.-1/8 mm.		18.15
Quartz	78	
Plagioclase	7	
Chlorite	5	
Hornblende	4	
Phlogopite	4	
Orthoclase	1	
Muscovite	.6	
Shell fragments	.2	
Biotite	.1	
1/8 mm.-1/16 mm.		24.80
Quartz	83	
Hornblende	7	
Chlorite	4	
Plagioclase	3	
Muscovite	.8	
Orthoclase	.8	
Phlogopite	.3	
1/16 mm.-1/64 mm.		8.68
Quartz	89	
Hornblende	9	
Plagioclase	1	
Chlorite	.9	
Phlogopite	.4	
Orthoclase	.2	
Less than 1/64 mm.		3.18
Clay	56	
Quartz	44	
Total Sample		
Quartz	57.08	
Igneous and metamorphic pebbles	15.78	
Plagioclase	6.73	
Shell fragments	6.02	
Hornblende	3.99	
Chlorite	3.34	
Clay	1.78	
Vegetable matter	1.78	
Orthoclase	1.28	
Phlogopite	1.24	
Muscovite	.78	

All the samples contain in general the same minerals and differences in mineral content are largely due to the differences in the quantity or order of frequency. Some of these differences are due to differences in texture, for a certain size grade may in all the samples contain a large proportion of a given mineral. If that grade is large a larger proportion of the given mineral will show in the mineral content

percentages of the sample as a whole. There are two primary reasons for this: (1) The original crystals in the parent rocks were of about the same size. Hornblende, for instance, tends to occur in small crystals in the granites and diorites from which it is derived. Hornblende is more abundant in the finer grades of the sediments and hence a sample which is texturally fine will contain more hornblende than a coarser sample. (2) The position of a sample relative to waves and currents determines the major and accessory textural grades and likewise governs shape and specific gravity sorting which have a bearing on the mineral content of a sample.

Glacial drift is the principal source of sediment in the Bay. The mineral content of all the samples is similar. There are more varieties of minerals than would occur if only one kind of rock was being eroded along the bay border which could hardly be the case in this region. If different types of rock were being cut away the mineral content should show local differences. The glacial drift is more likely to be homogeneous in containing at every place a wide variety of minerals whose localization would soon be obscured by the further mixing by littoral transport and beach drift. All of the samples contain relatively high percentages of minerals which would not persist under extreme conditions. It does not seem likely that the wave cutting of solid rock would allow such grains to survive in such large numbers. With greater distances from the nearest source the percentages of these minerals would decrease.

SUMMARY

SOURCES OF THE SEDIMENTS

There have been several agents responsible for bringing the sediments into Massachusetts Bay. Small streams, wave cutting along the shore, rain wash, glaciers, icebergs, and the wind have each played some part.

Streams. Few streams of any consequence flow into the sea along this coast. What small streams there are have low gradients near their mouths and probably do not contribute much in the way of sediment except for clay and silt. Where these rivers empty into the bay along fairly open coasts, this fine material is probably transported out to deep water. Near shore it may constitute part of what is called the shifting load. In some of the quieter bays, such as Salem Harbor, the analyses of sediment show the presence of colloidal clay and vegetable matter characteristic of river-borne sediment [see analysis of Series V; sample 2 (02968)]. The accumulation of silts and clays, then, is not confined to the deeper water, but occurs also in shallow bays which are sufficiently protected from the waves. Very likely rain wash may be an important factor in carrying fine material into the sea at these places.

Waves. Wave erosion along the coast supplies a large part of the sediments which are being carried into the ocean at present. To the south along

the outside of Cape Cod the cliffs are being worn back rapidly and deposition of sediment must be comparatively rapid as a result. Along the drumlin coast south of Boston, a fairly large amount of sediment must be derived from the cliffs cut in glacial deposits, although the presence of rock bottom at a short distance from shore (pl. 2) makes one wonder what happens to this sediment. Farther north, the cliff-derived material is probably important as shown by the steepness of the sea cliffs and the land-tied islands, beaches, etc., but the erosion is necessarily slower because it must remove fairly resistant rock.

Along the north shore between Nahant and Gloucester the ocean bottom was examined, directly off some of the sea cliffs. In some places the waves must have been so violent as to have carried away all the material broken from the cliffs. In most other places sand was found right up to the solid rock, without a trace of pebbles. Also, water-worn pebbles derived from the cliffs were not found farther out. In some coves along side the cliffs there are beaches which have pebbles ranging up to 10 or 12 inches in diameter. There are graded, with the coarser material at the high tide or storm wave level and the finer pebbles further down the slope.

Glacial deposits. There is no indication that the glaciers during the Pleistocene were restricted to the shores of Massachusetts. Cape Cod is clearly of glacio-fluvial origin and to the northeast Nova Scotia was overrun by ice. It is probable that the ice margin was far beyond the limits of Massachusetts Bay. Certainly much of the sediment has glacial aspects. Angular pebbles, some of them several inches in diameter, found in various parts of the bay in clay and silt deposits, as well as in sand, are apparently ice-borne material, but might be the products of icebergs. Most of the sands are unweathered and have a great variation of types of material suggesting that they were either deposited by ice in the bay or have been washed from glacial material on shore. In the drumlin region this is of course not difficult to understand, but the same sands occur elsewhere.

The presence of scattered pebbles in the various deposits suggests that there has been very little deposition since the retreat of the Wisconsin ice sheet. The broad expanse of what appears to be bare rock surface adds weight to this suggestion.

Stellwagen Bank. The discussion of glaciation leads to a consideration of the origin of Stellwagen Bank. Cape Cod is a glacio-fluvial ice contact deposit. Stellwagen Bank as seen from Plate 1 is a northward submarine continuation of this cape. A transverse profile of the ridge is shown in Figure 19. Comparison of the sediment on this ridge with that along the outside

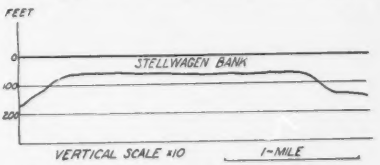

FIG. 19. A transverse profile of Stellwagen Bank.

of Cape Cod shows a general resemblance. This leads to the conclusion that Stellwagen Bank is also a glaciofluvial ridge. There is a moraine on Cape Ann to the north of the Bank, and also another submarine ridge extending out beyond Cape Ann to the northeast. One peculiarity is common to both of these submarine ridges; there is fairly deep water between the mainland and the ridges. Whether this is just a coincidence or whether it has some bearing on their origin is difficult to say.

TRANSPORTATION

Neglecting any transportation which may have been accomplished by glaciers or icebergs during the Pleistocene, the sediments have been transported by a combination of storm waves and currents and tidal currents probably with some wind transportation around Cape Cod. Raymond and Stetson[8] recognized another factor in the transportation along this coast. In sediment traps they found that jelly-like masses accumulated rapidly. This they believed was capable of transporting sediment even as coarse as sand during storms and thus causing the roiling of the waters frequently observed along the coast. The efficiency of the storm waves as compared with tides varies a great deal from place to place. In general, the tides are relatively unimportant along the open coasts, and wave action is negligible in the bays.

Effects of wind waves. D. W. Johnson[9] and others have shown the effect of wind waves and currents in distributing sand and gravel. If the wind is blowing at an angle towards the shore, the tendency of the water to pile up is counteracted by a long-shore drift, which carries the material away from its source and forms beaches, spits, and bars to one side. If the wind is blowing directly in towards the coast, there is necessarily a return seaward by which sediment is moved away from the beach. The motion near shore is probably not continuous, but is interrupted if not reversed temporarily by incoming waves.

Around Massachusetts Bay there are many examples of long-shore drifting. The beaches mentioned above which adjoin the cliffs were in most cases built in the direction in which the storm winds blow, although often against the prevailing westerly winds. As mentioned previously, beneath the cliffs there is only sand, although pebbles occur to one side. This would appear to indicate either that the pebbles are more easily transported by the drift during storms as they present a greater surface or that the only place where pebbles may be preserved is on the beaches where they are not dashed against the cliffs and ground to sand.

The beach which adjoins the cliffs on the outside of Marblehead Neck is subjected to severe wave action. The pebbles are distributed in size somewhat as shown in Figure 20. The large boulders at "A" have not been carried from the cliffs to the east or

[8] Raymond, P. E. and Stetson, H. C. *Science* (n.s.) vol. 77, pp. 105-106, 1931.

[9] Johnson, D. W., *Shore processes and shoreline development,* pp. 123-125, 1919.

they would grade into smaller sizes away from the cliffs. A small ledge at "A" had contributed the adjacent boulders of large size. In general, the debris seems to have been derived in part by wave erosion of the ledges along the cove and in part from the transportation of the coarse particles from the adjacent cliffs by long-shore currents.

In some places it was found that the grade of the sediment instead of varying from coarse to fine going out from shore varies in the other direction. One notable case of this is in the vicinity of Nahant. Off Nahant to the west there are gravel deposits. These grade into fine sand going towards Revere Beach and also become finer going out to sea. The gravel appears to be derived from the headland of Nahant and is probably washed to its present position during heavy storms when the wind blows from the southeast. The finer material which is washed into the bay may be carried shoreward by a current which moves in on the east side of Broad Sound and out on the southwest side. This current is probably reversed at times when the wind blows from the south, thus forming the connection between Revere Beach and Winthrop Highlands. Off other parts of the coast, for example off Highland Light on Cape Cod, there are alternations between fine and coarse material rather than a progressive decrease in grain size outward. Since one of the criteria for telling the direction of an old shore line by sedimentary rocks has been to try to find the direction of the coarser material, it is quite important that such evidence as presented above should be taken into consideration.

Tidal Action. In general, tidal erosion is not nearly as important as the effect of storm waves, but in some

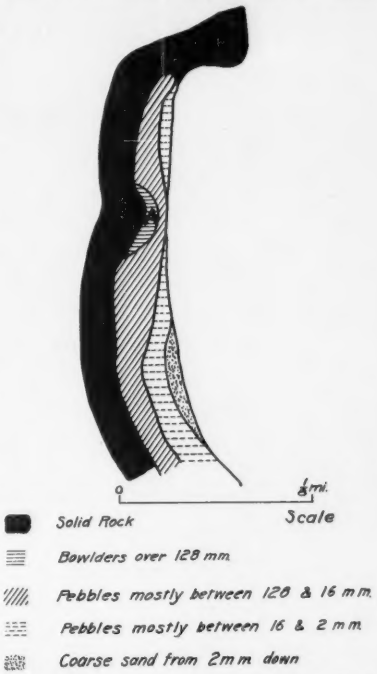

FIG. 20. The beach south of Great Head on Marblehead Neck.

places it becomes very significant. There are several estuaries where the current moves from 2 to 3 miles per hour. In one of these, Beverly Harbor, there is a tidal channel with steep sides. The sediments were examined from the shore to the north out into the channel and a decided change was found at the edge of the channel. The strong current in the channel does not

eliminate fine material, but brings a mixture of coarse and fine material together. At the end of Cape Cod there is a tide strong enough to move much material. Presumably the rapid growth of the end, 525 feet in 8 years, is greatly influenced by the tide, although wind induced currents no doubt have also been a factor. Perhaps the shallow trench which surrounds the end of the Cape (fig. 14) is a result of the concentration of tidal energy upon approaching the Cape.

The tide crossing a bank often runs very strong. The current is very perceptible over Stellwagen Bank and probably prevents the deposition of all fine material such as is being deposited in the depression to the west.

UNCONFORMITIES

If the tides continue to delay sedimentation over the Stellwagen Bank ridge while sediments collect in the deep water on either side, the final burying of the top of the ridge may be delayed till the adjacent deeps have been built up nearly level with it. Future exposure of the resulting section might show something like that in Figure 21. Here one sees the relations typical of erosional unconformities. The ridge would have the appearance of having been an island during the deposition of layers on the side.

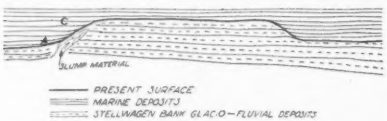

FIG. 21. Possible future burying of Stellwagen Bank. This might suggest erosion followed by partial submergence while the Bank stood up as an island. The actual history would be deposition of ice contact outwash deposit, followed by submergence, and deposition on either side but not in the center because of the tide.

A rise in sea level such as would result from the melting of the Antarctic ice cap would presumably put an end to the special sedimentation conditions which exist at the end of Cape Cod. Imagine what difficulty one would have in correctly interpreting the unconformable relationship which would develop from the burying of this spit and its lateral depressions. Figure 22 is an attempt to show the kind of a structure which might develop. The contact between the spit and the channel filling would probably be irregular because of slumping down the steep contact slope during the filling stage.

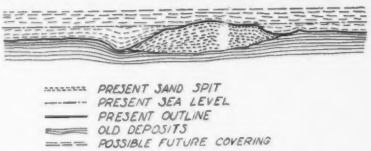

FIG. 22. Showing the stratigraphic section which might result from a rise in sea level causing the submergence of the end of Cape Cod.

CHANGES IN LEVEL

There appears to be good evidence for an uplift along Cape Ann and in many places further north as many writers have said. There is also some evidence of post glacial submergence in the Bay. Numerous soundings have been taken on Stellwagen Bank. They show that its surface is remarkably flat with depths close to 80 feet, over

almost its entire length. To the south a small mesa rises above this surface with depths of about 60 feet. It seems probable that these two levels represent successively developed marine abrasion platforms. The flatness suggests that the cutting did not go far below sea level.

The sea cliffs in the hard rock along the North shore are for the most part bordered by relatively deep water. Since wave-cut cliffs should have shallow wave-cut terraces adjacent to them, this unusual relation suggests drowning. The rocky islands around Marblehead also give the appearance of being drowned hills rather than wave isolated stacks.

Thus there is evidence both of elevation and of sinking in the Massachusetts Bay region. Possibly these changes are a combination of rising sea level due to melting of the ice caps followed by a slow rising of the land due to relief of the pressure of the ice.

ROCK BOTTOM

As has been mentioned, there are considerable areas of rock bottom indicated on the chart. Because of the water depth, sampling apparatus is not competent to tell whether there is actually ledge rock or merely large rock fragments. Whichever situation exists, one must explain the absence of fine sediment. Possibly the glaciers scraped off the sediments from these areas and currents and waves have been powerful enough to prevent later covering. Another possibility is that the sediment might have been washed off by the waves when the sea was lowered by the locking up of ice in the continental glaciers. The bare rock outer islands of the Norwegian Strandflat show the effect of former glaciation followed by wave attack. Submergence of these islands would produce a very rocky sea bottom.

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FORMATIVE PROCESSES IN CONCRETIONS FORMED ABOUT FOSSILS AS NUCLEI

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ABSTRACT

The concretions under consideration are unusual in that they contain an exceptionally high percentage of uncombined alumina in an anhydrous state or in a very low state of hydration.

Their present chemical character has been developed largely through the influence of compounds liberated in the decomposition of crabs about which they were formed. Their physical characters have been determined by internal forces due to chemical reactions, external pressures due to crustal movements, and variation in the permeability of the inclosing clays in different directions.

The chemical and physical forces traced in this study are believed to be typical of many of those involved in the development of concretions of more common chemical and mineralogical character.

OCCURRENCE

The alumina-bearing concretions herein described occur within the Crockett member of the Cook Mountain (Eocene) formation of Brazos county, Texas. The principal collecting ground for the specimens studied was along the banks of the Little Brazos River in the vicinity of the Bryan-Stone City highway bridge, 8.4 miles, by speedometer reading, west of the Missouri Pacific railroad station in Bryan.

The upper part of the exposed section, which is the concretion-bearing portion, is as follows:

SECTION OF CONCRETION-BEARING BEDS NEAR BRYAN, TEXAS

	Thickness, in feet
Dark brown, weakly indurated clay shale	12
Brown glauconitic marl	3
Greenish brown, friable, glauconitic marl	5
Gray to yellow impure limestone carrying highly developed cone-in-cone	11

Below these beds occur others of a similar lithologic but different paleontologic character.

Mineralogically there are two types of concretions, to one or the other of which all specimens may be referred. These may be designated respectively as black concretions and red concretions.

The black concretions are so called because of the dark color of the core which makes up their bulk. This core may be in direct contact with, or in substitution for, the shell and body of an inclosed fossil crab. The core is surrounded by a thin, compact case of yellowish tinge. The concretions are spherical, spheroidal, or midway between spheroidal and discoidal in shape. Two of the smaller specimens studied, and a very few of the larger, are molded to indicate the outline of the contained crab.

The red concretions are nearly

TABLE I. SIZES OF CONCRETIONS

Concretions	Equatorial diameters in mm.	Vertical diameters in mm.	Ratio of vertical to mean equatorial diameters
Smallest specimen	19×20	15	1/1,3
Mean average of all specimens	54.6×55.8	39.5	1/1.4
Largest specimen	102×135	69	1/1.9

round or roughly molded to the outline of a contained crab.[1] They carry a high content of ferric oxide in the form of hematite and this gives them a red-brown color throughout. They are somewhat sandy and are coarser in texture than those of the black type, which may account for their higher impregnation of iron.

Because the red type is represented by fewer specimens, is of less paleontologic importance, and indicates less clearly the processes of concretionary development the remainder of this discussion will be devoted to a consideration of the black type.

PHYSICAL PROPERTIES

Table I gives in condensed form the results of measuring 69 specimens. Thirteen of these have a form partly molded to the outline of a crab. These include all individuals, except one, whose maximum diameter is over 93 mm. Only two concretions smaller than the mean average size show the influence of a crab in shaping the outline. Eight of the specimens that show shaping effects are between the average size and 93 mm. in maximum diameter.

[1] The crabs of these concretions are described by H. B. Stenzel: *Jour. Paleontology* (to be published in 1932).

The typical concretion consists of three parts: case, core, and fossil.

The case varies slightly in thickness over different parts of the concretion. This variation shows no definite relationship either to the concretionary form or to the contained fossil. The limits of variation are between 1/20 and 1/13 of the radius of the concretions. The color varies from yellowish-brown to yellowish-gray. Thorough cleaning of the weathered exterior often reveals a surface checkered much after the pattern of a golf ball. This pattern is the outward expression of interior block jointing. The lower surface of the case may rest upon the core, or directly upon the carapace of a crab.

The core varies in color from dark reddish-brown to blue-black. It is always divided into polygonal, pyramidal, or prismatoid sections by from two to four sets of radial joints. The distances between adjacent joints is three or four times as great as between the block joints of the case. The jointing is comparable in character to that produced by the hydration of anhydrate to gypsum or to that produced in the laboratory by the hydration of starch under pressure. Such joints may be produced by shrinkage

TABLE II. CHEMICAL ANALYSES OF CONCRETIONS[a]

Oxides	Percent of core	Percent of case
SiO_2	4.94	36.60
CaO	12.80	13.97
MgO	5.15	1.37
Fe_2O_3	2.49	7.23
CuO	0.20	0.00
MnO	0.065	0.00
Al_2O_3	57.50	23.30
TiO_2	0.00	0.00
H_2O	3.21	5.56
CO_2	7.00	5.79
P_2O_5	5.32	3.24
SO_3	1.22	0.97
Moisture	—	1.18
K_2O (by difference)	0.105	—
TOTAL	100.000	99.21

[a] Analytic work by P. J. A. Zeller, chemist of the Texas Engineering Experiment Station.

on drying or as a result of compressional forces.

A system consisting of concentric circular joints roughly parallel with the outer surface of the concretion is also present. As many as three of these concentric joints may cross a radial joint between the center of the core and its contact with the case.

CHEMICAL AND MINERALOGICAL PROPERTIES

Table II shows the chemical composition of the case as contrasted with that of the core. In thin sections of the case, the calcium is seen to be accounted for as calcite and crystalline calcium phosphate. Aluminous clay minerals and quartz represent the bulk of the case in which iron oxide and other minerals are imbedded. The calcite is much more abundant in the outer than in the inner portion of the case. It is found in scattered crystals and concentrated in thin, regular bands parallel with the surface.

Recalculation of the chemical into mineral analysis will not give exactly the mineralogical composition of the core of the concretion, but chemical

TABLE III. MINERAL ANALYSIS OF CONCRETIONS

Minerals	Per cent of core
Amorphous and cryptocrystalline alumina	58.1
Calcite and dolomite	15.3
Collophanite	12.2
Quartz	5.2
Iron oxide minerals and magnetite	2.5
Aluminum hydroxides	2.3
Magnesium sulphate	1.9
Glauconite, copper and manganese minerals (by difference)	2.5
TOTAL	100.0

and microscopic studies combined give the following approximately correct results (Table III).

The order of formation of salts in aqueous solutions was determined from the *Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists, 1924,* and applications made on the basis of chemical affinities in aqueous ammonia-bearing solutions near atmospheric temperatures and pressures over long periods of time.

In the recalculations no attempts were made to carry out the small amounts of potash, manganese, and copper. The magnesium was first combined with the sulphur as sulphate and the balance with calcium and carbon dioxide in the form of dolomite. The remaining carbon dioxide was then combined with the calcium as calcite. The remaining calcium was just about sufficient to balance off the phosphorus as collophanite. The iron oxide minerals include hematite, turgite, and limonite, to which magnetite must be added. The silica was all carried out as quartz. The alumina was combined with all the water as aluminum hydroxides and the remainder carried out as alumina.

Quantitatively the alumina, calcite, and collophanite are the important matrix constituents. These form the ground mass in which the other minerals are imbedded.

The calcite occurs as fragmental shell material, as minute crystals, and as disseminated matter in the matrix.

The collophanite has the appearance of the amorphous calcium phosphate of ordinary phosphorite. It occurs as a colloidal solid.

The iron oxide is found as reddish hematite and turgite, and as yellowish limonite coloring the matrix. Near the contact of the core with the case the amount of iron oxide is usually greater, and the ratio of hematite or turgite to limonite increases. Iron oxide veins are also present, and in these the red minerals predominate over the yellow. Magnetite grains occur within the glauconite.

Most of the glauconite appears as smooth, round or oval, polished grains imbedded in the matrix. The grains vary from 0.01 mm. to 2.4 mm., the average size being about 0.1 mm. in diameter. The color varies from green to yellowish gray to nearly colorless depending on the varying iron content.

In the core, silica occurs as quartz in small grains. Amorphous silica is probably present also. This conclusion is based on the very small amount of definitely crystallized quartz visible in thin-sections. In the case, the quartz is more abundant and the grains are larger. Fibrous chalcedony is also present in considerable amount. Both the quartz and the chalcedonic silica is remarkably free from inclusions.

The copper minerals consist of smears of malachite and azurite and minute grains of sulphide, probably bornite or covelite. These occur on the planes of the radial joints.

ORIGIN OF THE VARIOUS MINERALS

In considering the origin of these minerals we may divide them into three groups: (1) Those that were

constituents of the original clay and were included within the concretions without katamorphic change, (2) Those produced within the concretion by the katamorphism of some of the inclosed clay minerals, and (3) Those produced by synthetic processes and whose constituents came, in part at least, from the crab.

The first of these groups includes the quartz grains of the core and the glauconite. So far as these form parts of the concretions they represent simple inclosures of the surrounding clay. The iron oxide minerals and part of the calcite belong to this group also. These latter represent material carried in from the surrounding clay and precipitated within the concretions.

The second, or katamorphic group, comprises the cryptocrystalline and colloidal alumina of the core and most of the silica of the case. Study of the surrounding clay shows most of the alumina in it to be in the form of the crystalline hydrous aluminum silicates. The transition from the aluminum silicate of the clay to the cryptocrystalline and colloidal alumina of the core is a problem the solution of which is involved in any theory of the origin of the concretions.

It is a well established fact that ammonia precipitates aluminum hydroxide from aluminum salts. It is equally well known that carbon dioxide and sodium carbonate precipitate aluminum hydroxide by the transient formation of the carbonate which immediately hydrolizes. With regard to the chemical character of amorphous ammonia-precipitated hydroxides of aluminum and iron Hagiwara[3] states: "Either no definite hydrates existed at all, or there are many of them . . . the smallest rise or fall of temperature would suffice to convert a higher into a lower hydrate or *vice versa*." Ammonia and/or carbon dioxide production are never failing accompaniments of the decay of animal tissue, and in the present instance must have been supplied by the decomposition of the crab. Amorphous aluminum hydroxide and hydrated oxides are the chief constituents of bauxite. They occur in many clays and soils although the crystalline hydrargillite is also present.

The free silica within the concretion, whether occurring as quartz or in the chalcedonic form, must, to a large extent, represent the precipitation or coagulation of silica liberated by the desilicating process and subsequent dehydration.

The third group includes the collophanite, the copper minerals, the traces of magnesium sulphate, and part of the calcite.

The collophanite and calcite undoubtedly had their origin in the shells of the crabs, which, according to analyses of spider crabs by Clarke and Wheeler,[4] contain 8.73 to 16.03 per cent calcium phosphate, 73.07 to 78.58 per cent calcium carbonate, and 1.22 to 2.24 per cent calcium sulphate.

The copper minerals comprise

[3] Hagiwara, Tokutaro, in *Colloidal Chemistry*, Alexander, vol. 1, p. 648, 1926.

[4] Clarke, F. W. and Wheeler, W. C., The inorganic constituents of marine invertebrates. *U. S. Geol. Survey*, Prof. Paper 124, p. 44, 1922.

TABLE IV. PHYSICAL PROPERTIES OF COMPOUNDS IN THE CONCRETIONS

Compounds	Molecular weight	Molecular volume	Heat of formation
Kaolinite[a]	258.83	89.2	3954
Cryptocrystalline Al_2O_3	102.2	25.5	1630
Colloidal silicic acid	96.33	61.3	1397
Water	18.02	18.0	286
Quartz	58.6	22.1	83
Diaspore	180.3	53.0	—

[a] There is no intention to imply that the clay of the inclosing formation or that of the original concretion body is kaolinite, but the kaolinite formula and physical properties were used in a generalized sense as representing a hydrous aluminum silicate.

minute traces of malachite, azurite, and the sulphides, probably bornite and covellite. One of the characteristic constituents of the blood of crabs is a copper compound, haemocyanin.[5] It is a well-known fact that copper has been precipitated in nature by organic solutions. Copper has a higher affinity for sulphur than any other metal present. The writer believes that the copper minerals in the concretion were formed by reactions between the haemocyanin of the crab's blood and hydrogen sulphide and carbon dioxide evolved by bacterial decay.

The presence of small amounts of magnesium sulphate to account for the balance of the sulphur is purely hypothetical and is postulated on the greater affinity of magnesium for sulphur than that of any other metal present save copper. All but a trace of the sulphur present was therefore recalculated as combined with the magnesium.

ORIGIN OF THE PHYSICAL CHARACTERISTICS

In discussing the origin of the physical characteristics of the concretions it is necessary to consider the energy and volume changes involved in the desilication of clay. Table IV gives the physical properties of the compounds involved in the process.

In the desilication of clay in an ammonium or carbon dioxide environment at approximately atmospheric temperatures and pressures, which would obtain at shallow depths, the reactions could be expressed as follows:

(1) $Al_2H_4Si_2O_9+2H_2O=Al_2O_3+2H_4SiO_4$
(2) $Al_2H_4Si_2O_9+5H_2O=2Al(OH)_3+2H_4SiO_4$
(3) $Al_2H_4Si_2O_9=Al_2O_3+H_4SiO_4+SiO_2$

The first and second are the more likely types of reaction. Substituting values in these formulae we find indication of the liberation of 874 kilojouls of heat evolved per gram formula weight of hydrous aluminum silicate in the first instance and 102 kj. per g.f.w. in the third. Figures on the heat of formation of diaspore are not available for calculating the energy changes in the second formula. In any event the amount of heat produced when distributed over the time involved in the reactions seems wholly inadequate to have accumulated sufficiently to cause pressure jointing through expansion.

[5] Schmitt, Waldo L., Curator of Marine Invertebrates, U. S. National Museum, Letter to the writer June 7, 1928.

Calculating the volume changes involved in these same reactions through molecular rearrangements we find 62.8 per cent increase on the first formula, 27.6 per cent increase on the second, and 22.2 per cent increase on the basis of the third.

Roughly speaking the crabs occupied, on the average, about one-half the volume now included in the concretion, the other half of the volume being occupied by the clay. The above calculated expansion was confined to the clay portion and the percentages must therefore be approximately halved to average them into the entire volume of the concretion. On assuming the reactions to have been about equally divided between the types represented by equations one and two an expansion of about 23 per cent must have resulted. There is no doubt that the pressures produced by volume increases in the katamorphism of the clay would have been sufficient to produce the pressure-jointing now preserved in the core provided the case had already been indurated. The production of the radial joints evidently preceded the final rearrangement of the copper and the silicification of the case since the copper-bearing solutions certainly, and the case-hardening silica solutions probably, utilized them as channels for circulation. It would seem, therefore, despite the strong argument for pressure-jointing, that the radial joints must have formed along the lines of solution movements after completion of the bauxitization of the clay and the induration of the case.

The dehydration of diaspore to amorphous alumina involves a 51.9 per cent decrease in volume after the elimination of the water. As the products of bauxitization are normally less fully hydrated than diaspore, the actual shrinkage involved in the interior of the concretion would be much less than 51.9 per cent, but nevertheless effective in producing many open joints. The formation of these shrinkage joints by dehydration of the colloidal hydrate followed the development of the case. Therefore, both the radial and circumferential joints are believed to have been formed by the dehydration of the bauxitized aluminum matrix.

The fact that the case is to a large extent the outer zone of the core case-hardened by the secondary deposition of silica carried outward as a by-product of bauxitization has already been stated. This makes its formation contemporaneous with the decomposition of the organic part of the crab and the desilication of the clay, and prior to the dehydration of the colloidal aluminum hydrate. The joints of the case are not structurally related to those of the core. These facts, together with the observation that there were no volume-reducing chemical reactions carried out in the case, compel the search for some external force acting upon the concretion which could have produced them. Such is found in many evidences of pressure in the surrounding clays. These comprise slickensides in the clay adhering to the concretions, bending in the clay beds, and the strongly developed adjacent lay-

ers of cone-in-cone. The case is a self supporting shell and it is the theory of the writer that it had attained approximately its present chemical, physical, and crystalline properties, with the exception of its joints, prior to the pressures exerted on the beds externally. The closely spaced, closed jointing and slight flattening are the reactions of a competent crust to these forces.

The shape and size of the concretions has been determined by four factors: (1) the shape of the crab, (2) the size of the crab, (3) the physical character of the inclosed clay, and (4) the subsequent external pressures which produced the pressure phenomena in the surrounding formation. Of the first of these there is little evidence except in those forms noted as having been shaped to the crab. The second influenced only the factor of size. The fourth was effective only in producing a shortening of the vertical axis. The third was the chief shaping factor. The clay appears to have been first desilicated and later dehydrated radially outward as far as the organic solutions from the decomposing crab reacted effectively. The factors determining the lengths of these effective radii of reaction from the center of the crab would be equal in all directions so far as textural differences in the clay did not exist. The longer diameter of the crab in the horizontal than in the vertical plane together with greater permeability parallel with the bedding planes of the clay caused a greater length of horizontal than of vertical radii of development in most instances.

SUMMARY

The steps in the development of these concretions may be listed as follows:

1. Burial of the crabs during the process of sedimentation.
2. Decomposition of the crabs liberating ammonia and carbon dioxide solutions which were instrumental in desilication and bauxitization of the immediately surrounding clay.
3. Radial spreading of the bauxitization process with deposition of the liberated silica on the fringe of activity, resulting in case-hardening of a subglobular envelope.
4. Chemical and mineralogical rearrangement of the magnesium, calcium, potassium, copper, phosphorous, and carbon of the crab's body and skeleton and the calcium, magnesium, aluminum, iron, and manganese of the clay.
5. The nearly complete dehydration of the rearranged aluminum colloid.
6. Development of shrinkage joints in the core by the dehydration processes.
7. Dessication and partial devitrification of the silica of the developing envelope.
8. Development of compression joints in the case by external pressures accompanying the crustal movements subsequent to sedimentation.

These steps have been listed in the order of their inauguration, but except for the first and last there has been an overlapping of the time element so that steps 2 to 6 and the initial parts of step 7 operated more or less simultaneously.

NOTES

ORGANIC STRUCTURES IN SEDIMENTS

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In a recent discussion of "sporbo" by the writer[1] the objects were considered "as being in the same general category as the phosphatic nodules described in the Challenger report."[2] The idea that the objects might be excrement was not considered plausible. At the time of that publication the writer had been a "connoisseur" of excrement for about six months and until then had seen nothing that resembled "sporbo," unpyritized or otherwise. Moreover, he had been able to make unpyritized "sporbo"-shaped objects by precipitating tricalcium phosphate in lyophilic gel[3] media such as agar, gelatin, and compact clay. The work was in accord with that published by Lloyd and Moravek.[4]

At present, a considerably broadened experience with biological phenomena permits presentation of more data which have a bearing on the origin of the interesting objects called "sporbo." Chief inspiration in this study has come from Hilary B. Moore of the Marine Station at Hillport, Scotland, who has published several excellent articles[5] on the conditions of sedimentation in the Clyde Sea area. These reports should be of much value to every student of sediments and sedimentary rocks.

In the last publication mentioned Moore[6] has figured the excrement of a Maldanid worm (a species of *Rhodine*) which simulates "sporbo" to a remarkable degree. His line drawing is reproduced here (fig. 1a) and with it the line drawings of other similar excrement recently obtained by the writer from marine invertebrates collected in Monterey Bay, California.

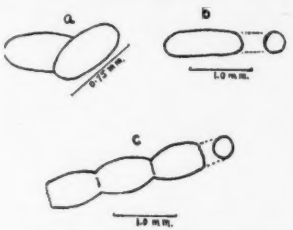

FIG. 1. *a*, Line drawing of the faecal pellets of *Maldanid-Rhodine* sp., from the Clyde Sea area. These objects are circular in cross section. After H. B. Moore.

b, Line drawing of the faecal pellet of the gastropod, *Tegula funebrale*, from Monterey Bay, California.

c, Line drawing of the bologna-like excrement of a Chiton (species unknown) from Monterey Bay, California.

The technique of obtaining such objects requires some patience. The greatest care

[1] Galliher, E. Wayne, Collophane from Miocene brown shales of California, *Am. Assn. Petroleum Geologists Bull.*, vol. 15, pp. 257-269, March, 1931.

[2] *Op. cit.*, p. 269.

[3] A lyophilic gel is a colloidal mass, the constituent particles of which are each partially or wholly surrounded by a water mantle. This sort of mass has a profound influence on the growth of included crystals.

[4] Lloyd, Francis E., and Vladimir Moravek, Further studies in periodic precipitation, *Jour. Phys. Chem.*, vol. 35, pp. 1512-1564. See especially figure 83, p. 1559.

[5] Moore, H. B., The muds of the Clyde Sea area, 1. Phosphate and nitrogen contents, *Jour. Mar. Biol. Assn.*, vol. 16, pp. 595-607, 1930; The muds of the Clyde Sea area. III. Chemical and physical conditions; rate and nature of sedimentation; and fauna, *idem.*, vol. 17, pp. 325-358, 1931; The specific identification of faecal pellets, *idem.*, vol. 17, pp. 359-365, 1931.

[6] *Op. cit.*, p. 363.

is required to keep intact the faeces voided in laboratory aquaria, and it is nearly impossible to preserve excrement collected in the field; that is, from tidal flats and shallow-water estuaries. The fragility of the objects is due to their being small, loosely bound aggregates of clay and minute mineral particles.

Mr. Moore has kindly supplied the photograph of the thin section of a faecal pellet of a species of a Maldanid worm, genus *Rhodine*, reproduced in Figure 2. It is his opinion "that the structures you describe ("sporbo") are most probably the pellets of some invertebrate."[7]

The pyritization of the pellets involves the reactions outlined in the writer's previous paper.[8] Their phosphatization may probably be accounted for on the basis of their action as centers of attraction for phosphates. Such a process is not thoroughly understood, but is profusely covered by the term "diagenesis."

It is difficult to overestimate the value of the study of such objects, for they may add a vast amount of information to the interpretation of the "palecology" of a sediment; that is, to the ecologic conditions in the environment at the time the sediment was deposited. The systematic study of such excrement is apparently an open field for examination, and Mr. Moore is to be commended for his interest in the matter.

Finally, it is desirable to point out the possibility of confusing other objects with true faecal pellets. Thorp[9] has mentioned that a number of inorganic structures may be confused with excrement. Moreover, flocculated clay on the sea bottom may take shapes resembling small faeces by the mere oscillatory motion of the water. This motion causes the floccules to form rounded, incoherent pellets.

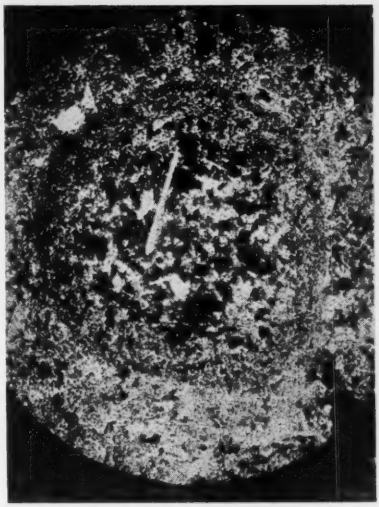

FIG. 2. Photomicrograph of the thin section of a pellet of *Rhodine* sp. from Clyde Sea muds. Sectioned *in situ*. Greatly magnified. Courtesy of Hilary B. Moore.

February 13, 1932.

[7] H. B. Moore, Personal communication.
[8] *Op. cit.*, pp. 267-268.
[9] Thorp, E. M., Descriptions of deep-sea bottom samples, *Bull. Scripps Inst. Ocean.*, Tech. ser., vol. 3, pp. 1-31, 1931.

DISCUSSION

THE OCCURENCE OF MOISSANITE (SILICON CARBIDE) IN SEDIMENTS

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Many sediment-petrologists who have read the paper of Messrs. R. D. Ohrenschall and Ch. Milton[1] will be familiar with the presence of blue grains with the optical properties of carborundum in slides of heavy residues of sediments. The attempt of the authors to derive the grains from the original sediments seems to be new and, of course, the authors have considered the possibilities of contamination by industrial carborundum during sampling and laboratory treatment.

With regard to this explanation I should like to direct the attention to the work of the Dutch geologist, J. H. Druif,[2] on the origin and mineralogical composition of the loess in the province Limburg (Netherlands). In this book the occurrence of carborundum in some of the slides prepared by Druif is described and fully explained through a rather unexpected manner of contamination. The carborundum grains turned out to originate from the polishing paste with which the laboratory taps were cleaned. The quotation, translated into English follows here:

> Contamination of samples or fractions during laboratory treatment only rarely occurred. Only one typical case repeatedly occurred, the cause of which could not be traced in the beginning.
>
> In several of the first slides prepared, varying amounts of a strongly colored substance with a very high index of refraction and low birefringence were noted. As a rule the grains were very angular, their color is generally blue, but also bluish green and green grains were occasionally found. At first I thought that the substance was anatase, and later on, corundum, but both suppositions turned out to be false. Then I could identify the material to be carborundum as used in preparing thin-sections, but this determination did not simplify the question about the possible manner of the contamination. Several possibilities were traced without any result. The only fact that could be established was that the troubles occurred more or less periodically, sometimes very strong, sometimes not at all. At last the solution of the problem was discovered. It proved to be the water-tap being cleaned with a polishing paste containing carborundum. After every cleaning something of the material rested behind and could come by the hands of the investigator in the water of the elutriation apparatus. Being rather coarse, with a high specific gravity, the material came in the sand fractions and after that in the heavy residues.
>
> In order to check this supposition the tap was thoroughly cleaned and its residue examined; the carborundum appeared in large quantities. When polishing the taps with the paste in question was stopped, the contamination ceased completely. . . .

From my own experience I can fully confirm Druif's conclusion. Before I had taken sufficient precautions, the grains occurred in many slides prepared in my laboratory but afterwards the "mineral" has never been observed by me any more.

Before the origin of the grains as indicated by Messrs. Ohrenschall and Milton is accepted by other investigators, the explanation as given by Druif should be fully considered.

[1] This *Journal*, vol. 1, pp. 90-99, 1931.

[2] Druif, J. H., *Over het ontstaan der Limburgsche loess in verband met haar mineralogische samenstelling*, Utrecht, 330 pp. 1927. See pp. 214-215.